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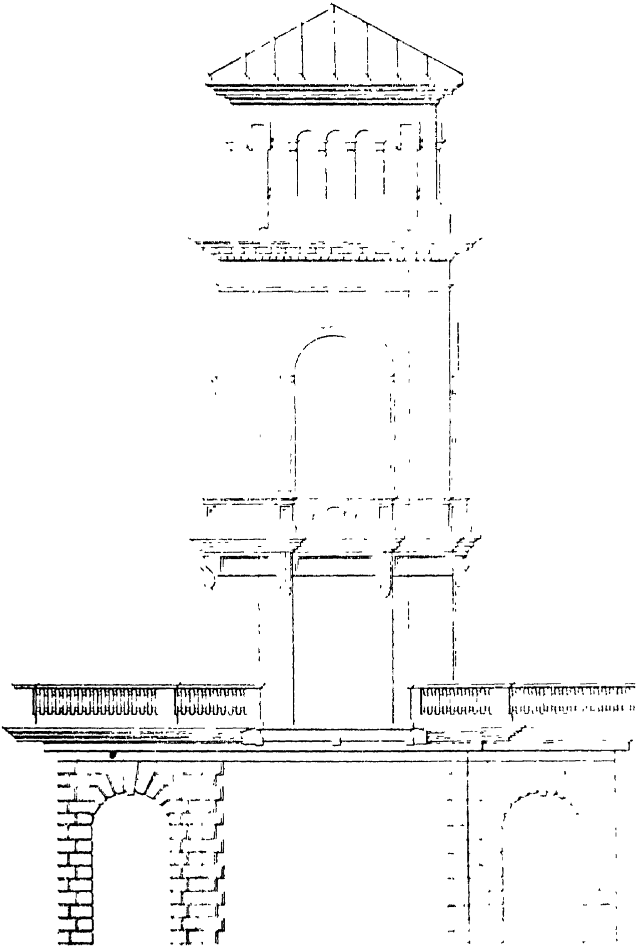
CHARING CROSS BRIDGE

Elevation of Pier



THE
RUDIMENTS
OF
CIVIL ENGINEERING,

BY HENRY LAW,
CIVIL ENGINEER;

AND

THE RUDIMENTS
OF
HYDRAULIC ENGINEERING,

BY G. R. BURNELL,
CIVIL ENGINEER.

JOHN WEALE, 59, HIGH HOLBORN.

LONDON:
GEORGE WOODFALL AND SON,
ANGEL COURT, SKINNER STREET.

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THE RUDIMENTS
OF
CIVIL ENGINEERING.

PART III.

SPECIAL CONSTRUCTION.

The Charing Cross Suspension Bridge.

THE Charing Cross Suspension Bridge, which has lately been constructed over the Thames by Mr. Brunel, has been selected, as affording one of the latest and by far the best example which could be found of this kind of bridge.

The general dimensions of this bridge have been given in the table at page 147 of the Second Part; and the details of its construction are exhibited in the accompanying plates, figs. 105 to 118. It has been explained in the First Part*, that in order that the chains of a suspension bridge should be equally strained throughout, their sectional area should vary according to the inclination of the chain, being greatest at the piers, where the chains are most inclined, and least in the center, where they are horizontal. Charing Cross Bridge is, however, the only one of all those mentioned in the table which has the area of its chains thus varied, according to the varying strain; in all the others the chains are parallel, or of equal sectional area throughout; but in the case of the Charing

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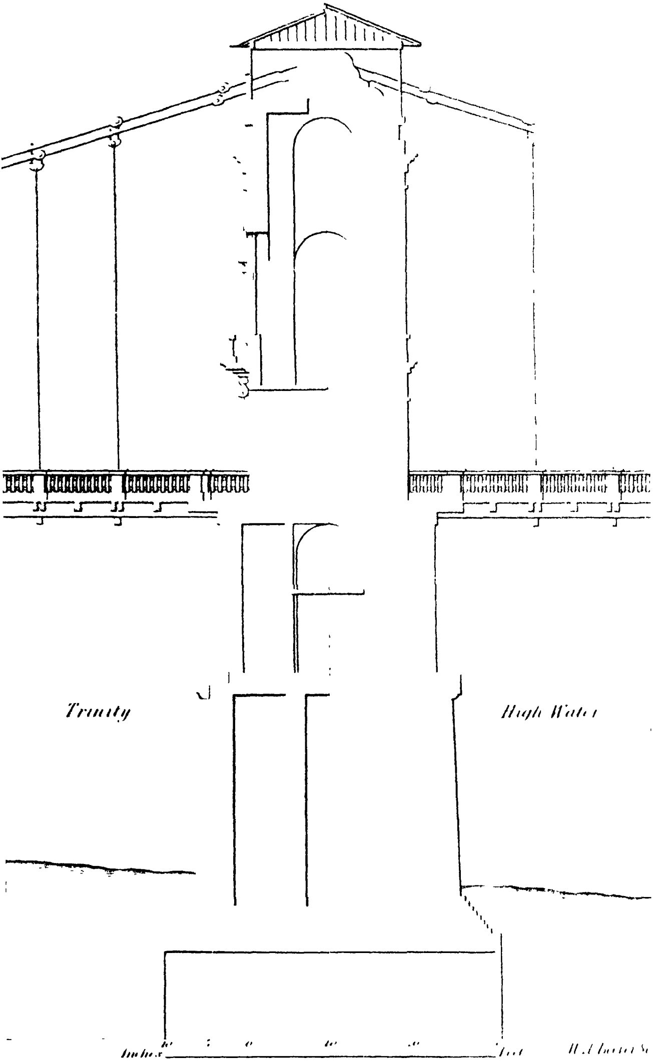
* Page 60.

Cross Bridge, the chains vary from 296 square inches in the center to 312 square inches near the piers.

The bridge consists of three openings, that in the center, which has a span of 676·5 feet, forming a complete catenary, and the two side ones, which are each 339·9 feet, forming semicatenaries. The superstructure of one of the piers is shown in elevation in fig. 105; and fig. 106 is a transverse section upon the line C D E F, fig. 109, of one of the piers entire, affording also a longitudinal section of a portion of the platform, a transverse section of which is shown in the previous figure; a longitudinal section of the lower portion of the pier is given in fig. 107, and a sectional plan of the same in fig. 108; while fig. 109 exhibits two horizontal sections of the superstructure of the piers, that on the right hand being taken through the basement below the platform, and that on the left hand through the pier above the same. From these it will be seen that the whole of the pier is constructed upon the principle which we advocated for those of all kinds of bridges, namely, that of being formed hollow, in such a manner as to combine the requisite size of base to insure stability, with as little weight as possible. Had the piers of this bridge been built solid, instead of as they have been, their weight would have been increased in the proportion of 1 to 1·7. By an examination of the sections, figs. 106 and 109, it will be seen that the weight of the chains is received and transmitted to the lower part of the pier by four square pillars or piers of brickwork, each side of which is 7 feet 3 inches, and which form the angles or corners of the campanile tower. These piers are steadied and connected together by the walls of the same, except where the latter are pierced to form windows or doorways. Below the platform the dimensions of these piers are somewhat increased, as shown in the right-hand half of the sections, figs. 106 and 109. The foundation of these piers below the basement is formed by a solid mass of brickwork, 7 feet 6 inches wide, running entirely across the piers, as shown in figs. 107 and

CHARING CROSS BRIDGE

Section of Pier



Charing Cross Bridge

Fig 107

Longitudinal Section of Pier

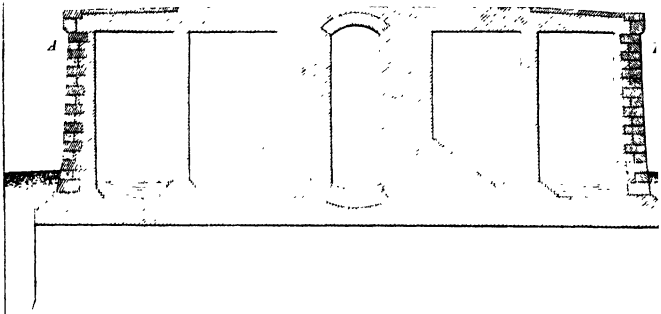


Fig 108

Sectional Plan on the line AB

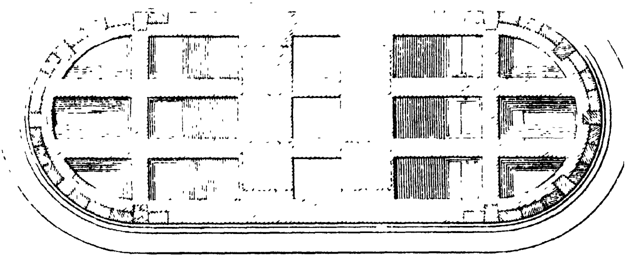
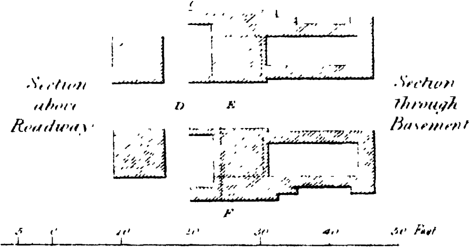


Fig 109



108, on the latter of which the position of the detached piers above is shown by dotted lines. These walls, or masses of brickwork, are spread out at their base in steps, as shown in the figs. (107 and 108), so as to throw the weight which they carry over a very large surface; and, in fact, by means of the side and transverse walls, which are well bound together with hoop iron, the weight may be considered to be as completely and uniformly distributed over the whole surface of the ground upon which the pier is founded, as if the whole had been a solid mass. The ends, or cutwaters, of the piers, as shown in figs. 107 and 108, are faced with stone, as being the parts most exposed to injury. The piers have not any piles under them, but are surrounded by a row of close sheet piling (as shown in figs. 106 and 107), to prevent the possibility of the piers being disturbed by any deepening of the river; although, from their proximity to the low-water line of the shore, there is very little probability of any considerable alteration taking place in the level of that part of the river's bed.

The construction of the north or Hungerford abutment is shown in figs. 113 and 114, the former of which is a longitudinal section showing the manner in which the ends of the chains are secured, and the latter is a transverse section taken on the line A B in the former.

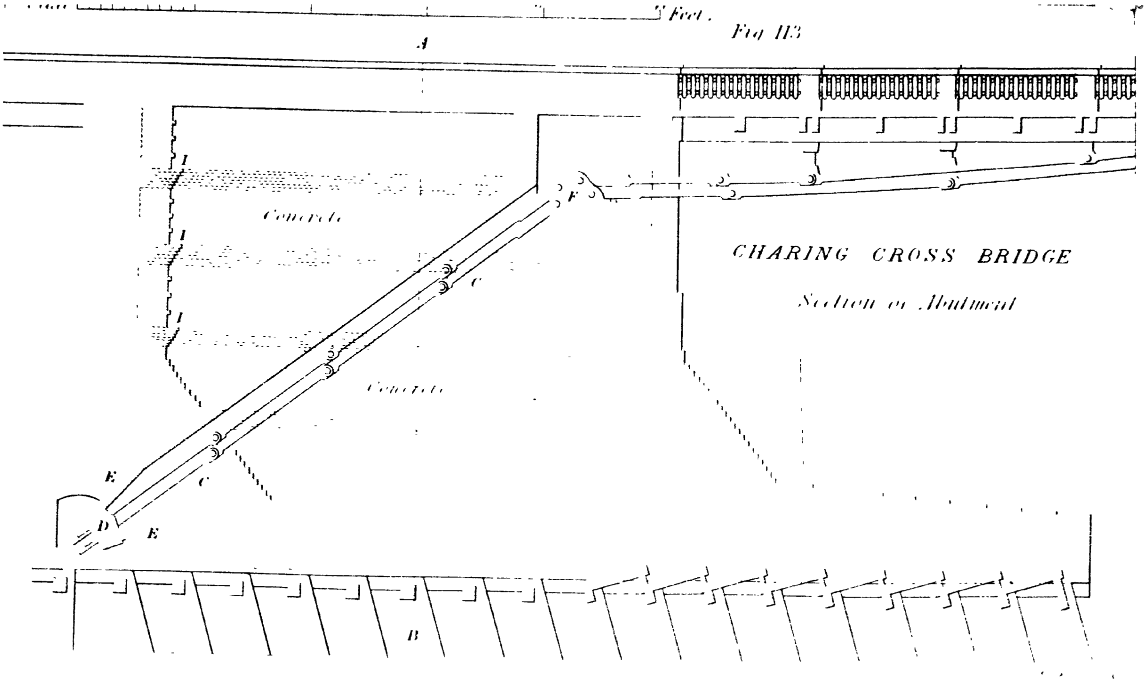
In the general remarks which we made upon the subject of the abutments of bridges, we stated that they, as well as the piers, should be so constructed as to possess as little weight as possible; the abutments of suspension bridges are, however, exceptions, the office which they have to perform being totally different from that of the abutments of an ordinary bridge. The purpose which the abutment of a suspension bridge is intended to serve, is that of holding and retaining immovably the ends of the main chains; and it is therefore evident, that the larger the mass and the greater the weight of the abutment, the less likelihood there will be of its being disturbed.

It will be seen, by a reference to fig. 113, that the chain where it enters the abutment is nearly horizontal, and, therefore, so is also the direction of the strain which it produces, tending to pull the abutment forwards into the river. This tendency is, however, counteracted in a great degree by the very judicious manner in which the piles are arranged. In the abutment of an ordinary bridge it is usual to make the piles slope towards the arch, so as to receive its thrust nearly perpendicularly; in this case, however, the nature of the strain is quite different, and, were the piles driven in the ordinary manner, they would have offered but comparatively a slight resistance. In this case, therefore, they have been made to slope in the contrary direction, or away from the river, as shown in the section 113, so that the abutment cannot move forwards, in the direction in which the chains solicit it, without forcing every pile to move in the same direction, and consequently to assume a less inclined position, in doing which, as they may be supposed to turn upon their lower extremity as a center, it is obvious that they would have to lift or raise the whole mass of the abutment bodily, which would require an enormous force, in addition to that necessary to overcome the resistance which the ground would oppose to the motion of the piles, by its pressure against their front surfaces.

As, therefore, the weight of the abutment in this case adds to its stability, it was formed nearly of one solid mass; but as the cost of so large a quantity of brickwork would have been very considerable, it was formed hollow, as shown in the sections, figs. 113 and 114, and the spaces thus left were filled in with concrete. The space in which the north abutment had to be built being limited by the proximity of the Hungerford Market, the piles were carried out beneath the level of the shore in front of the abutment, as shown in fig. 113, the pressure being distributed over them by the manner in which the brickwork was stepped down.

Before explaining the manner in which the main chains were secured to the abutments, it will be well to describe the

Fig 113.



CHARING CROSS BRIDGE

Section on Abutment

CHARING CROSS BRIDGE

Details of Saddle

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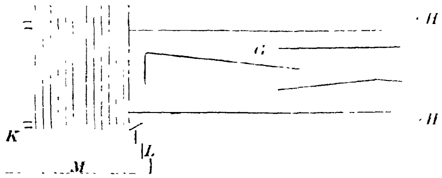
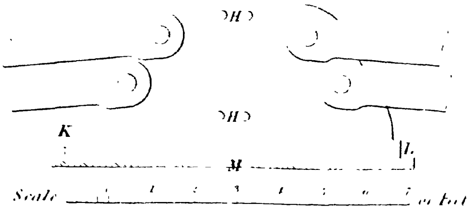
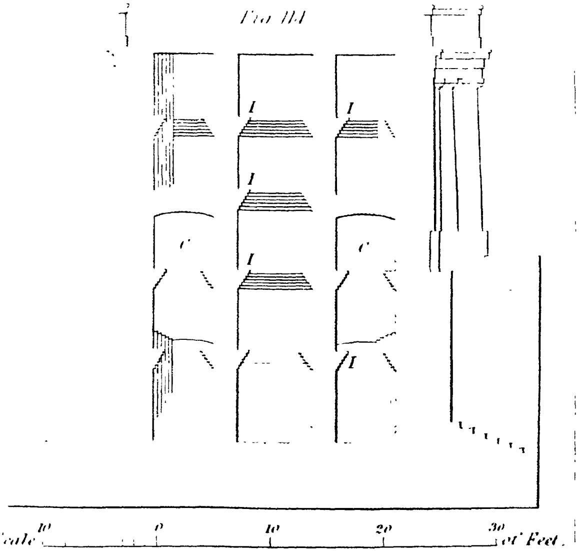


Fig. 11b



Section of Abutment

Fig. 11d



W. A. Beever Sc

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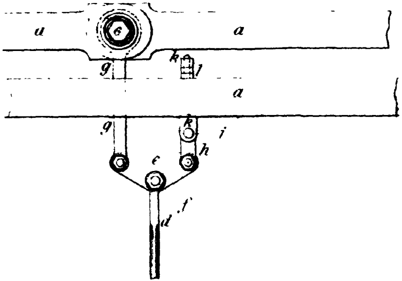
Charing Cross Bridge

Details of the Chains

Fig. 110



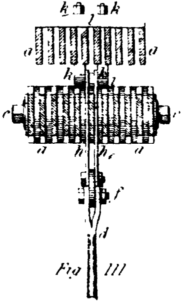


Fig 111

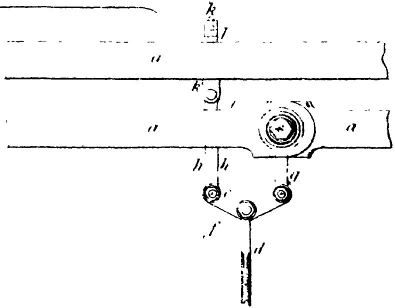
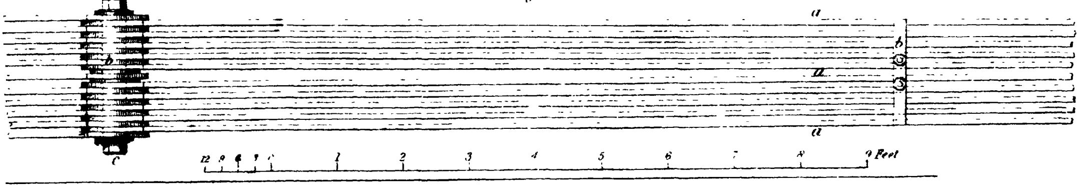


Fig 112.



chains themselves. By an inspection of fig. 104, it will be seen that there are four separate chains, two on either side of the platform, being placed one above the other, and having the suspending rods by which the roadway is supported connected with both chains, in such a manner that each receives an equal portion of its strain. Fig. 110 is a side view of a short portion of one pair of chains, broken in the middle to afford space for the transverse section of the same, fig. 111; and fig. 112 is a plan of the upper chain. Each chain consists of ten and eleven links alternately; these, *a a*, are of wrought iron, 7 inches in depth, and of such a thickness (about an inch) as to give the requisite sectional area, which, as already stated, varies with the inclination of the chain. These links are terminated at each end by an enlarged part, through which an eye or hole for the reception of the coupling pin was drilled, the distance apart of the centers of the two holes being exactly 24 feet. The links of one portion of the chain being arranged parallel to each other, with their eyes in the same straight line, and with about an inch space between them, those of the adjoining portion of the chain are introduced between them, so as to bring the eyes of the latter in the same straight line with those of the former, when a wrought-iron pin, *b*, $4\frac{5}{8}$ inches in diameter, is passed through them, and the chains are thus securely connected and coupled together; the pins are prevented from falling out by a cast-iron nut, *c*, screwed on to each end, as shown in the figures. This method of connecting the chains is a great improvement upon that which had always previously been employed, and which consisted in having the same number of links in every portion of the chain, and connecting them together by means of short coupling links; in this arrangement two pins were required at every joint, and consequently double the number which were employed by the arrangement here adopted. The links, as before stated, are 24 feet in length; but the chains are so arranged that the joints of the upper chain are precisely midway between those of the lower one, and as the suspending rods are attached to every joint, their distance apart is only 12 feet, as shown in fig. 106. Every one of these suspending rods is attached *to both* chains in the following manner: the end of the rod *d* is formed with a forked head (as shown in fig. 111), which embraces the lower part of a triangular piece of wrought iron, *e*, with which it is connected by a pin, *f*. This triangular piece is supported at each end by two small links, *g g* and *h h*; the former have eyes of sufficient size to admit the coupling pin, *b*, of the main chains, and are placed between the two center links of the same, the pin, *b*, passing through them, as shown in figs. 111 and 112; the latter, *h h*, are secured by the pin, *i*, to two short bolts, *k k*, passing through an iron bar, *l*, which lies across the whole of the links of the other chain, and by means of which they are all made to receive a uniform weight. The pin *f* being exactly midway between the points of attachment of the links *g* and *h*, the weight of the suspending rod, *c*, and its load, is equally divided between them, and therefore between the two chains to which they are connected.

We will now describe the manner in which the main chains are secured to the abutments. They approach it nearly horizontally, as shown in fig. 113, in which direction they proceed for about 10 feet, after which they are made to dip at about an angle of 37 degrees, passing down through two tunnels, C C, to the lower part of the back of the abutments, where they are securely held by strong keys, driven through mortised holes in the ends of the links, and which bear against twelve plates, D, placed between the links, and resting against two cast-iron girders, E E, firmly built into the solid brickwork. At the point where the direction of the chains is altered, both chains are connected to deep links, F, the bottoms of which are flat, and rest upon a cast-iron plate, K, as shown upon a larger scale in figs. 115*a* and 115*b*, forming a kind of saddle. Between the brickwork and these cast-iron bed plates a layer of several thicknesses of felt dipped in

Fig 116.

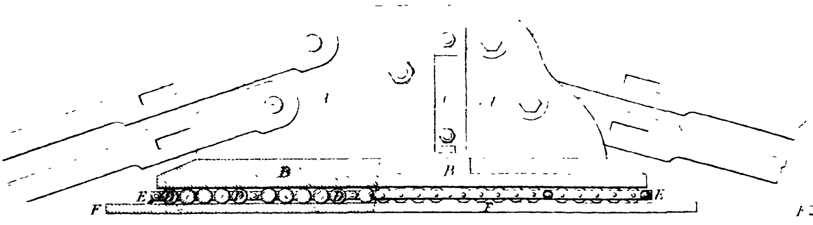


Fig 117.

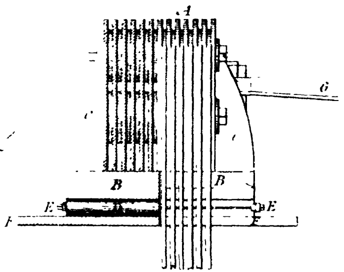
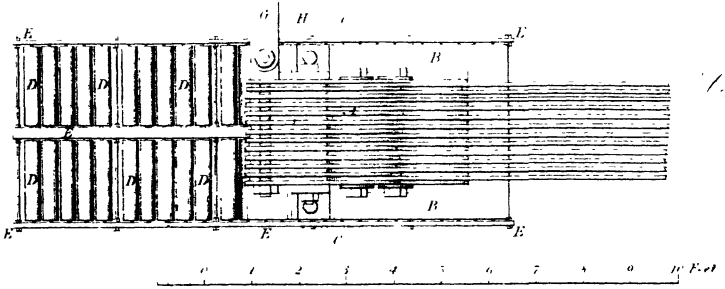


Fig 118.



Charing Cross Bridge

Details of Saddles

pitch, L, is placed, and beneath this a course of timber, M, 3 inches thick. The two saddles are connected together by a cast-iron stretcher, G, and four wrought-iron tie-bolts, H H, which pass through all the links or plates of both saddles.

Under these saddles the brickwork of the abutment is built quite solid, the other parts are formed hollow and filled with concrete, as already mentioned, the sides of the brickwork having projecting edges formed upon them, as shown at I I, to afford the concrete bond with the brickwork, and make the two constitute one solid mass.

We have yet to describe the saddles for supporting the main chains, on the top of the piers. It will be evident, upon examining the construction of the piers, that although capable of supporting safely a very considerable vertical pressure, they are not designed to resist any force acting horizontally, or such as would be brought upon them in the event of the strains upon the two opposite chains not being always equal if the chains were attached to the pier itself; a case which not unfrequently occurs, when, on the occasion of a boat race or any other attraction, a large number of persons congregate on the center portion of the bridge, leaving the sides comparatively unoccupied, and thus occasion a much greater strain upon the center chains than upon the side ones, which, if the chains were attached to the piers, would tend to pull them over. This tendency is, however, removed by placing the saddle to which the chains are attached on rollers, by which means it is capable of moving horizontally a certain distance, sufficient to allow the chains to rearrange themselves, under the influence of the unequally-distributed load, in such a manner as to be in equilibrium, that is, to have no further tendency to move, or to cause motion in the saddle or piers.

In figs. 116, 117, and 118, A A are the plates forming the saddle, to which both the upper and lower chains are connected, as already described in the abutment-saddle. These plates rest on a strong cast-iron plate, B, to which they are securely fixed by the standards, C C; this plate is supported upon fifty steel rollers, D D D, each 4 inches in diameter and 1 foot 9 inches in length, which are preserved in their proper positions by an iron frame, E E. The lower plates, F F, upon which the rollers run, are supported upon a very strong platform of timber and iron girders, by which the weight is uniformly distributed over the four pillars of brickwork, which we have before mentioned. The surfaces of both the plates B and F, in contact with the rollers, were planed perfectly true, and were galvanized to protect them from rust. The two saddles on each pier are connected together by a bar, G G, working on a center at H, by which, while the saddles are preserved at their proper distance apart, they are allowed the requisite freedom of motion.

The main points in this structure, to which we would more particularly direct attention, are the following:—The judicious manner in which the piers and abutments have been contrived to answer in the most perfect manner the office which they have to perform—the former, where weight would be an objection, as light as was consistent with the requisite strength, and the latter, where weight was required, formed as a solid mass, and the weight applied in the most judicious manner; the mode of attaching the suspending-rods which support the road way to the chains, so that every rod bears with *an equal strain on both chains;* and the manner in which the saddles which carry the chains on the top of the piers are arranged, to admit of perfect freedom of motion, and prevent any horizontal strain from being thrown upon the piers.

TUNNELS.

General Arrangement.

The importance of tunnels as a means of communication is so evident as to require no insisting upon in this place. The attention of the engineer was early devoted to their construction, and they have afforded a field for the development of some of the greatest proofs of his skill.

Their greatest utility is in situations where either tracts of elevated land or expanses of water which could not easily be spanned by bridges, interrupt the course of a railway, canal, or common road. The idea of cutting a tunnel or passage through elevated ground to avoid making a détour round it or a steep ascent over it, appears early to have suggested itself, but it is only in our own time that the more daring and difficult attempt has been made to undermine the beds of navigable rivers, and to establish beneath their waters a dry and secure means of transit. It is true that, founded upon a quotation from Diodorus Siculus, claim has been laid to the merit of having formed a subaqueous tunnel, on behalf of the Babylonians; but the account given by that historian is too much exaggerated to deserve much credit, and if true, his own statement shows that during the construction of the tunnel the river was diverted from its course, a ditch or trench being then excavated in what had been its bed, and a hollow passage of brickwork in bitumen built in it, after which the covering of earth was restored, and the Euphrates turned again to its old channel. The practicability of subaqueous tunnels having been now established, there is little reason to doubt that they will before long be much more generally used as a means of conveying railways across expanses of water, where, from a variety of causes, any of the more usual modes of crossing are not possible; and it therefore becomes of the more importance that the engineer should possess a knowledge of the means by which success has been attained.

Before any decision can be arrived at by the engineer, as to the course, levels, dimensions, and mode of construction to be adopted, careful surveys and examination of the strata geologically are requisite, together with levels or soundings from which a profile or section of the surface of the ground to be passed under may be made. The geological character of the strata must be ascertained either by borings, by sinking trial shafts or pits on the line of the intended tunnel, or by a small driftway or heading nearly following its course. The trial shafts thus sunk serve afterwards as working shafts through which the earth from the tunnel can be raised during its progress, and, by working either way from them, enabling the work to be carried on with great rapidity by breaking up the tunnel into short lengths, and, on the completion of the work, affording the means of light and ventilation. The advantage of a driftway consists in the more perfect drainage of the ground through which the tunnel is to be formed, and its insuring the certainty of the tunnel being formed correctly on the line intended. The nature of the various strata to be passed through having been accurately ascertained by one or other of these means, the engineer will be enabled to determine upon the best form of transverse section to be adopted for the tunnel, and upon the thickness of the masonry requisite to support securely the sides and roof; and he will be further enabled to judge of the probable amount of water to be met with, and to make such preparations, by the provision of proper and sufficient means of withdrawing it, as to prevent delays in the progress of the work. He will also, by such a particular acquaintance with the nature of the ground, be enabled to devise the simplest mode of securing the ground temporarily during the construction of the tunnel, and of anticipating and preparing for any difficulties arising from the varying character of the soil.

The subjoined table exhibits the principal dimensions of some of the most important tunnels which have been constructed, together with the general nature of the ground through which they were made, the name of their engineer, the materials of which formed, and their cost.

TABLE OF THE DIMENSIONS OF SOME OF THE PRINCIPAL TUNNELS.

Reference to Woodcuts.	Name and Situation of Bridge.	Purpose to which applied.	Extreme Height.	Extreme Width.	Thickness of Lining at Crown of Arch.	Length.	Nature of Strata.	Material of Lining.	Total Cost.	Cost per Yard forward.	Date of Completion.	Name of Engineer.
Fig.			ft. in.	ft. in.	ft. in.	Yards.			£	£		
118*a*	Thames and Medway Tunnel.	North Kent Railway.	39 0	35 6	1 2	3960	Chalk and fullers' earth.	Brick-work.	...	...	1800	W. T. Clarke.
119	Islington Tunnel ...	Regent's Canal...	21 6	20 0	1 6	900	London clay formation.	Ibid.	...	...	1812	Morgan.
120	Harecastle Tunnel .	Tetney Haven Canal.	16 2	17 0	1 2	2926½	Various strata	Ibid.	112,681	38½	1827	Telford.
121	Watford Tunnel	North Western Railway.	26 6	27 0	1 6	1830	Chalk	Ibid.	...	...	1838	R. Stephenson.
122	Box Tunnel, near Bath.	Great Western Railway.	36 6	36 0	2 3	3123	Freestone rock.	Ibid.	...	...	1838	I. K. Brunel.
...	Littleborough Tunnel.	Manchester and Leeds Railway.	27 6	27 0	1 10½	2860	Various strata	Ibid.	251,000	88	1841	G. Stephenson.
133	Under the Thames at London.	Foot passengers ..	22 3	37 6	2 6	400	London clay formation.	Ibid.	454,714	1137	1842	Sir I. Brunel.
123	Blechingly Tunnel .	South Eastern Railway.	30 0	30 0	1 10½	1324	Shale	Ibid.	95,237	71	1842	W. Cubitt.
...	Saltwood Tunnel ...	Ibid...............	30 6	30 0	2 3	954	Lower green sand.	Ibid.	112,542	118	1843	Ibid.

Fig. 118*a* is a transverse section of the tunnel constructed originally for the Thames and Medway Canal, but now used for

Fig. 118*a.*

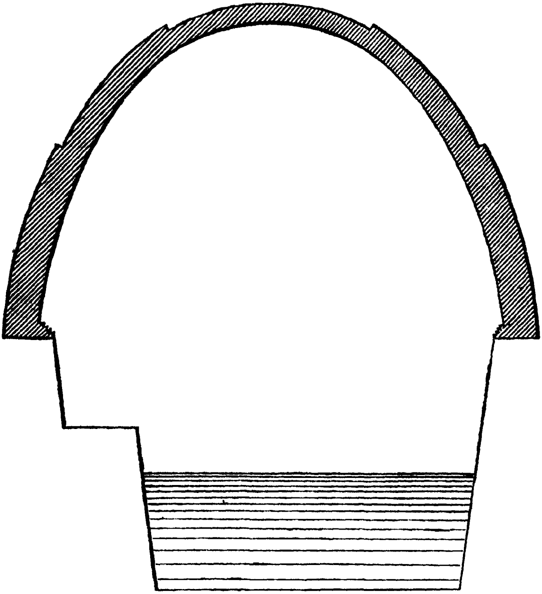


Fig. 119.

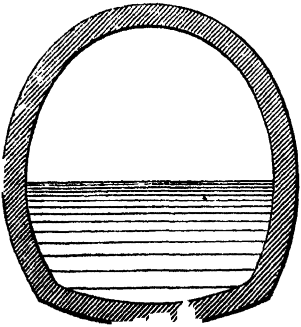
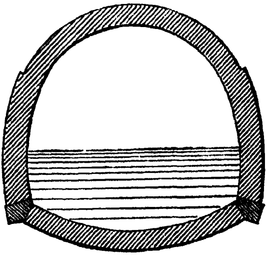


Fig. 120.



the North Kent Railway; fig. 119 is a section of the tunnel carrying the Regent's Canal through Islington; fig. 120 is a section of the Harecastle Tunnel on the Tetney Haven Canal, made by Telford, to take the place of a smaller one previously made by Brindley; fig. 121 is a section of the

Fig. 121.

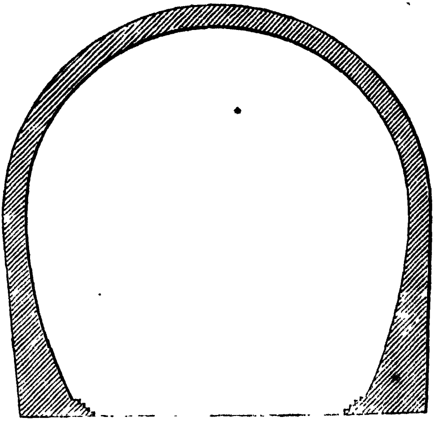
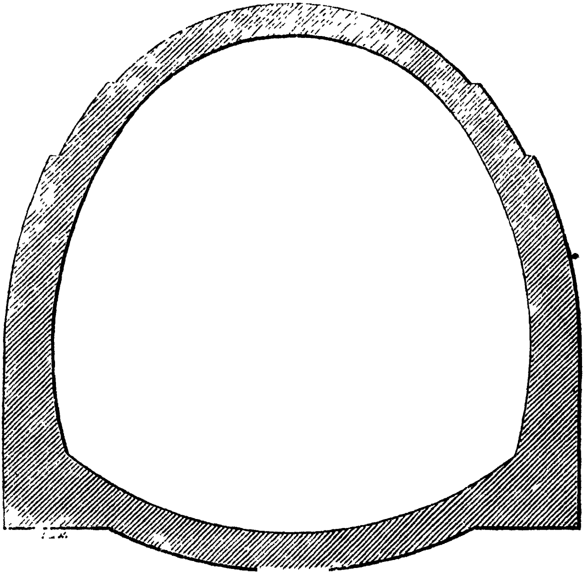
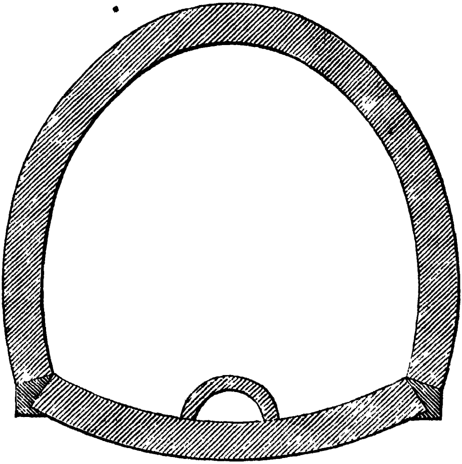


Fig. 122.



tunnel for the North Western Railway at Watford; fig. 122 is a section of the tunnel near Bath, for the Great Western Railway; and fig. 123 is a section of the Blechingly Tunnel, on the South Eastern Railway. The transverse section of the Saltwood Tunnel is precisely similar to the last, with the exception of being 6 inches greater in height. The whole of the foregoing sections are drawn to a uniform scale of 12 feet to the inch.

Fig. 123.



Mode of constructing ordinary Tunnels.

Having determined upon the exact course of the tunnel, the next point is, to arrange the position of the shafts. These are best placed at equal distances, and their frequency should depend upon the time in which it is necessary to complete the work. There is, however, a certain distance in every case which will be more economical than any other, and this will be readily understood if we bear in mind that the cost of the tunnel itself per foot forward becomes greater as its distance from the working shaft increases, so that by lessening the distance between the shafts and increasing their number, we diminish the cost of the tunnel itself; when, however, the shafts are placed too close, their cost becomes greater than the saving upon the tunnel, and there will therefore, in every case, be a certain distance, depending upon the relative cost of the tunnels and shafts, at which the expense of the whole work will be a minimum.

There are two methods in ordinary use for sinking the shafts: the first can only be followed when the ground through which it has to be sunk is tolerably firm and free from water, and consists in making an open excavation of the form and dimensions of the shaft, including space for the internal lining of brick or other materials, and to such a depth as the nature of the ground may indicate to be safe. A ring or *curb* (as it is technically called) of timber is then laid on the bottom of the excavation, previously levelled to receive it. This curb is formed either of one thickness with lapped joints, or in two thicknesses breaking joint (as shown at A A, figs. 124 and 125) securely bolted together. The thickness of the curb should depend upon the dimensions of the shaft, being in no case less than 3 inches; its internal diameter should

Fig. 124.

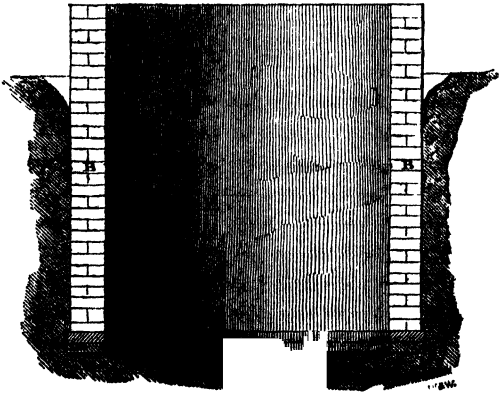
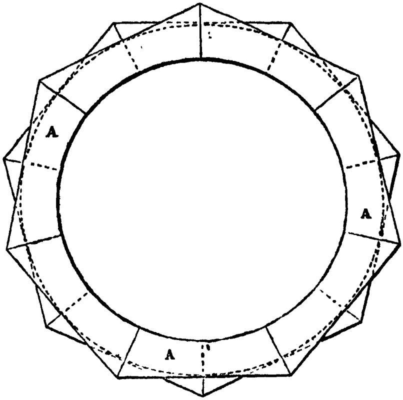
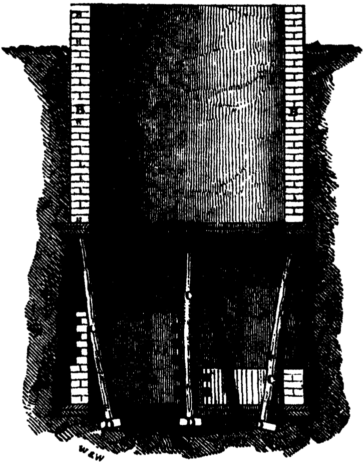


Fig. 125.



be the same as that of the shaft, and its breadth may be made greater, as shown in the figures, so as to project into the ground and assist in supporting the structure. As the curb becomes a part of the permanent work, it should be of oak or elm timber of the best quality. The curb being placed, the wall or lining (B B) of the shaft should be proceeded with, especial care being taken to ram in the ground firmly on the outer side, so as to leave no space or vacuity: indeed it is impossible, in all operations in tunnels and other subterranean works, to pay too much attention to prevent the slightest vacuity between the work and the ground; but, on the contrary, whenever the ground is at all loose or disposed to move, every inch of surface should be well supported, and not only supported, but well strutted against, so as to maintain an active pressure at all times against it. As soon as the brickwork forming the lining has been carried up to the level of the ground, and the earth securely rammed or *punned* in behind it, the excavation for a second length may be proceeded with. This, however, must be done with caution, so as not to endanger the stability of the portion already built, by undermining its foundation. We must first carry down the excavation in the center of the interior of the shaft, leaving sufficient ground under the curb safely to support it; we may then cautiously remove the ground from under the curb at four opposite points, leaving the intermediate ground to form piers

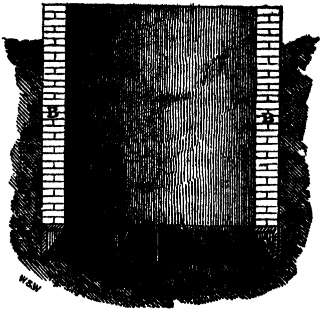
Fig. 126.



for its support. The spaces or recesses thus excavated afford the means of introducing shores or props for the temporary support of the curb while the remainder of the ground is being removed. These props should be placed in an inclined position, as shown at c c c, fig. 126, so as not to be in the way of the second curb; they should be spiked to the upper curb, to secure them from slipping out of place, and should rest at their lower extremity upon a broad sole piece, D D D, to prevent their sinking into the ground. The props having been introduced, the remainder of the ground may be removed, a second curb, similar in every respect to the former, laid at the bottom of the excavation, and the lining of brickwork proceeded with, in the spaces between the timber struts, in the manner shown in fig. 126. Upon the brickwork being brought up to the under side of the first curb, great care should be taken in perfectly filling up the space, so that the curb may have a firm and secure bed upon the brickwork below it. The props or struts may then be removed, and the brickwork completed in the spaces which they had occupied. The excavation should be again proceeded with, and the various operations already described repeated until the shaft has attained the required depth. The mode of building shafts which has just been described is technically termed *underpinning.*

The second method is frequently employed in sinking wells, and must always be adopted when the soil is too loose or full

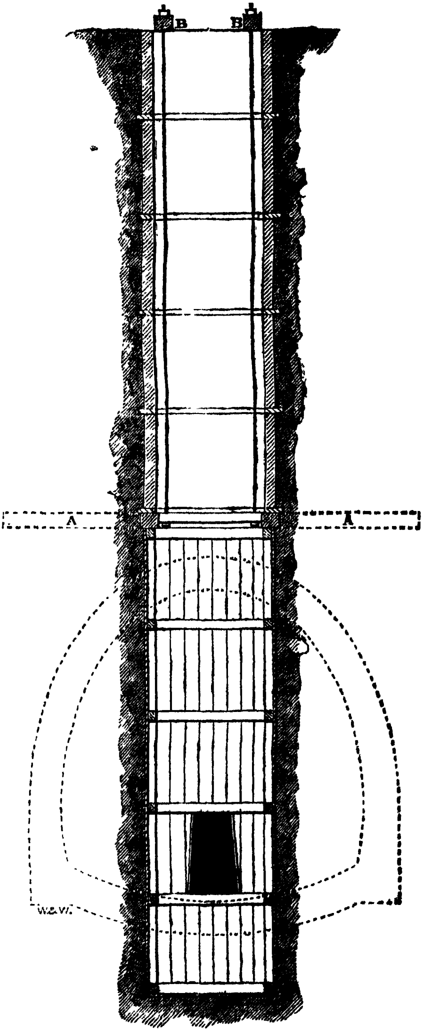
Fig. 127.



of water to allow of an open excavation being made with safety. It consists in forming the curb as shown at A A, fig. 127, with a sharp edge or rim, instead of having a broad flat surface, as in the former case; upon this curb the brickwork of the shaft is to be built as before until carried up to the level of the surface. The excavation within the shaft is then to be proceeded with, the whole of the ground being in this case removed from under the curb, which, being thus left without support, and being loaded with the weight of the brickwork upon it, will gradually descend; and thus, as the excavation is carried down, the curb will follow, and as it sinks the wall must be carried up, so as to maintain it level with the surface of the ground. The principal care required in this mode of sinking shafts is, to avoid one side of the curb descending more rapidly than the opposite one, by which the shaft would be thrown out of the perpendicular, and so much resistance occasioned as possibly to prevent its further descent. By a little management, however, in the removal of the ground from beneath the curb, this may be usually avoided; and, when earth-bound, the shaft may frequently be set free again by pouring water around it, so as to soften the ground on its outer side. A very good precaution against a shaft becoming earth-bound, is, to build it slightly tapering upwards; this tapering, however, should not be too considerable, otherwise the space left around it by the descent of the shaft would be sufficient to loosen and dislocate the surrounding ground.

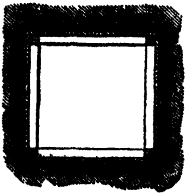
The brick shaft having, by one or other of these means, been carried down to within a few feet of the top of the intended tunnel, the excavation should then be cautiously

Fig. 128.



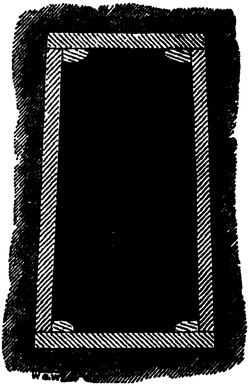
proceeded with, the sides being secured with timber framing and planks, until carried below the level of the bottom of the tunnel. Particular care should be taken that no movement in the ground takes place, because the difficulty of forming the tunnel would be greatly increased if the ground through which it had to be formed had been previously disturbed. The manner of securing the lower portion of the excavation with timber is shown in figs. 128 and 129, the former being a vertical, and the

Fig. 129.



latter a horizontal section. Previously, however, to carrying down the excavation below the brickwork of the shaft, some means must be adopted for its support, as the mere friction of the ground against its exterior surface would not be sufficient to sustain its weight. It is therefore necessary either to support it by introducing timbers underneath it, as shown at A A, in fig. 128, or to suspend it by rods secured to timbers resting on the surface of the ground, as shown at B B.

Fig. 130.



A small driftway or heading should now be commenced about the level of the bottom of the tunnel, and having a sufficient inclination given to it to enable any water met with to drain into the bottom of the shaft, which thus becomes a well or sumpt for the drainage of the works, and from which the water may easily be removed by any of the usual methods. The dimensions of the heading should be sufficient to enable a man to work in it without inconvenience. The usual size s about 3 feet wide and 5 or 6 feet in height; its sides should be secured with timber, as shown in the transverse section, fig. 130.

Fig. 131 is a longitudinal section of a portion of a tunnel in progress of construction. C, is the driftway, which has been carried forward to meet that from the next shaft, so as to form a continuous means of communication from shaft to shaft, the importance of which is considerable in enabling the direction and level of the tunnel to be set out without chance of error.

These preliminary works having been completed, and the form and dimensions of the tunnel determined, the excavation

Fig. 131.

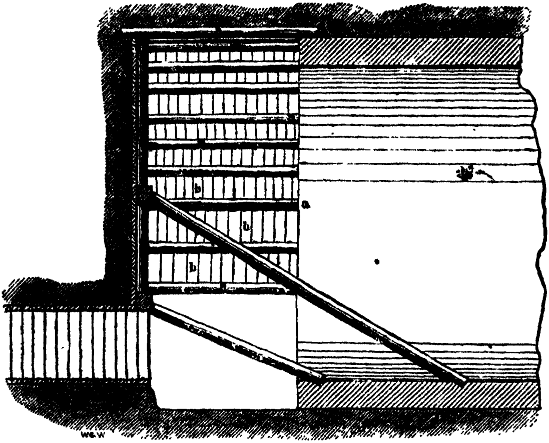
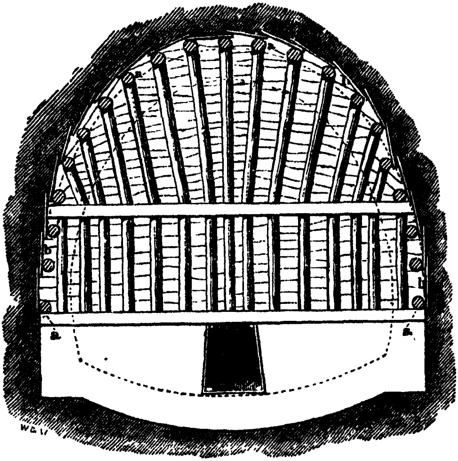


Fig. 132.



for it must be commenced, the ground being supported by means of timber and planks in the manner shown in figs. 131

and 132. The longitudinal timbers, *a a*, are termed *bars*, and the transverse planks, *b b*, *polings*. The length thus excavated at a time must depend upon the quality of the ground; but as it is always desirable that the surface of the ground should be exposed to the atmospheric influence for as short a time as possible, it is not proper to proceed too far before inserting the brickwork.

To insure the brickwork of the tunnel being true in form, curved templates are used for the invert and sides, while the upper portion is turned upon a center similar to those employed for turning the arches of bridges. As the brickwork proceeds, the bars and polings must be carefully removed, and any vacuity thus left must be filled with earth well rammed in, so as to prevent any settlement of the ground, which would occasion unequal strains upon the body of the tunnel. As in most strata some amount of settlement will take place in the superincumbent ground before the brickwork can be got in, the timber and polings should be placed a few inches above the top of the tunnel.

As soon as a length of brickwork has been got in on each side of the shaft, the temporary timber work of the lower portion of the shaft should be carefully removed, the ground excavated to the true form of the tunnel, and the brickwork introduced, being securely bonded with and connected to that already built on either side, and the brickwork of the shaft being carried down to meet that of the tunnel. When this has been properly effected, much of the danger and difficulty of the work may be considered as having been surmounted. The excavation of the face of the work must then be proceeded with, the top and as much of the sides of the work being supported by polings as may be found necessary, especial care being taken to prevent any disruption or movement of the ground. When the faces of the two opposite workings approach within a short distance of each other, great caution is necessary to avoid the thin partition of ground being disturbed. When sandy or other loose strata containing large quantities of water are met with, peculiar precautions must be taken to prevent the loose ground being washed in with the water, which would occasion cavities to be left in the surrounding ground ; it would, however, be equally dangerous to dam back and confine the water, and therefore such means must be resorted to as will permit the water to percolate into the work, but prevent the ground being brought with it : a very simple and effectual mode, under ordinary circumstances, is, to thrust straw into any opening from whence muddy water is found to proceed.

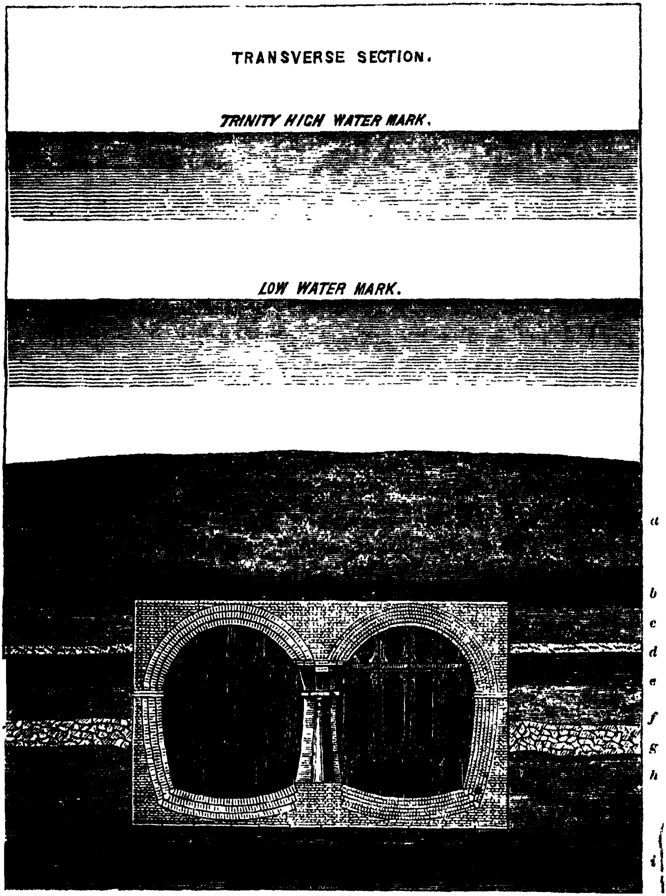
Upon the completion of the tunnel it is desirable that the shafts should be kept open, to afford light and the means of ventilation ; but, in order to avoid accidents, it is advisable to carry up the brickwork to a height of 8 or 10 feet above the surface of the ground, and to cover the opening or mouth with a strong iron grating.

Should the strata through which the tunnel has been constructed contain much water, a certain portion will be found to penetrate the brickwork, however carefully built, and in such a case a small drain or culvert should be formed along the center or lowest part of the invert.

Mode of constructing subaqueous Tunnels,

We shall now proceed to describe generally the mode adopted in the construction of the tunnel under the Thames between Rotherhithe and Wapping. The form of the tunnel will be understood by a reference to fig. 138, from which it will be seen that the external form is rectangular, the reason for which was, that the strata being horizontal, and, from their proximity to the river, subjected to constantly varying pressure, it was considered that a circular structure would have been exposed to very irregular strains. The archway was made double, in order that carriages might not have to meet and pass in the same opening, and the center or partition wall thus formed was pierced with frequent arches, as shown in the

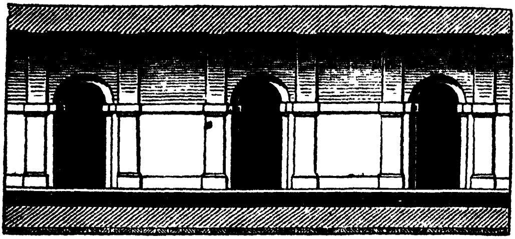
Fig. 133.



longitudinal section, fig. 134, which serve as a means of communication between the two archways, and form a very pleasing architectural feature in the tunnel.

The external dimensions of the excavation are—in height

Fig. 134.



22 feet 3 inches, and in breadth 37 feet 6 inches; its total length is about 1200 feet. The height of the archway is 17 feet, and the width of each on the springing line 14 feet; the upper portion is semicircular in form, and the side walls and invert segmental. The tunnel is built principally in half-brick rings, the thickness of the brickwork at the crown of the arch being 2 feet 6 inches, and the same below the invert, which is laid upon 3-inch elm planks. The external piers are each 3 feet thick on the springing line, and the center pier is 3 feet 6 inches. The right-hand half of the section, fig. 133, exhibits the mode in which the bricks were arranged when working in 9-inch rings, and the left-hand half when 4½-inch work was employed. The tunnel was built of the hardest picked stock bricks, laid in Roman cement of the best quality, those portions of the work which were most exposed to the action of the water being laid in pure cement, and the other portions in half cement and half pure sharp sand. The bricks for the semicircular arches are made in a wedge form, so as to produce parallel joints.

The section, fig. 133, is taken in the center of the tunnel, in the deepest part, showing the order and position of the various strata met with, as they would have been found if they had not been disturbed; from the constant runs of loose sand and the action of the water, especially on the Wapping side of the river, the strata, however, were usually found considerably dislocated and disturbed. In the section, fig. 133, *a* is a stratum of sand, gravel, mud, and river deposits; *b*, a bed of clay, of a reddish-brown colour; *c*, a stratum of clay mixed with silt; *d*, a thin layer of silt very full of shells; *e*, a stratum of stiff blue clay; *f*, a bed of clay of a more mottled character, containing a portion of silt and a number of shells; *g*, a stratum of indurated clay, which at times was so hard as to require wedges to break it up; *h*, a bed of gravel and sand of a green colour; and *i*, a similar stratum, but somewhat coarser.

The tunnel was commenced on the Rotherhithe side of the river in the year 1826, the shaft having been begun early in the previous year. The mode adopted in the sinking of the shaft was similar to that last described, the brickwork being built upon a sharp-edged curb, which descended gradually as the ground was removed from under it. When, however, the shaft had thus been sunk to a depth of 38 feet, it became earth-bound, and, although loaded with a considerable extraneous weight, and the water allowed to rise in the excavation for the purpose of softening the ground, no further movement took place; it was therefore determined to complete it by underpinning in the manner already described, and this, after much trouble and difficulty, arising from the loose nature of the ground, was successfully accomplished. When the shaft was sunk on the opposite or Wapping side of the river, the difficulties which had been encountered in the sinking of the former one were provided against, and the operation so successfully performed that the shaft was sunk to its entire depth (upwards of 72 feet) without becoming at all bound; this was principally owing to the shaft being made larger in diameter at its lower end, and the cast-iron curb being made of great strength.

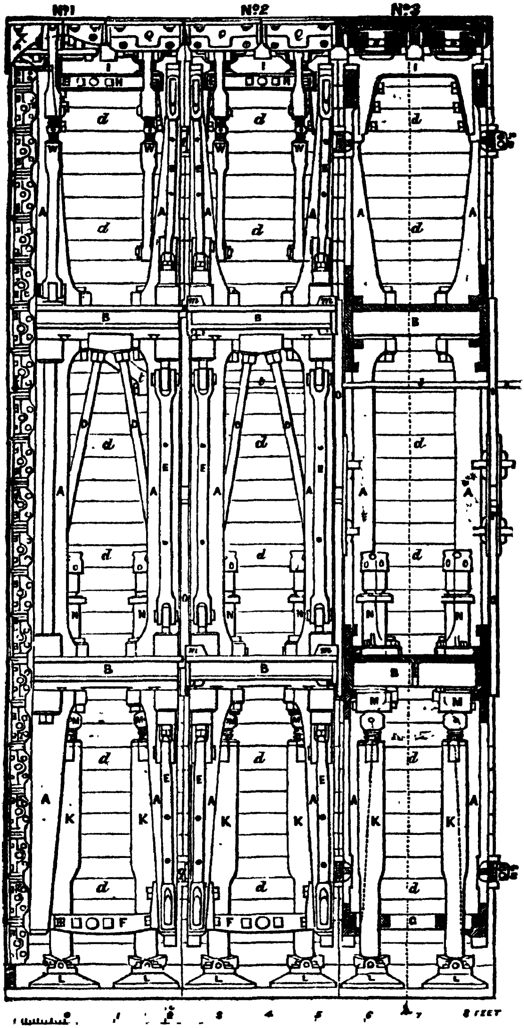
Our limits will not permit, and the object of the present work does not require, our giving a detailed account of the many casualties and difficulties which were experienced in the course of the work; we shall content ourselves with a general description of the mode in which the tunnel was constructed, and refer the reader who requires further details to the memoir of the Thames Tunnel in Weale's "Quarterly Papers on Engineering."

The mode of securing the ground already described as being employed in the case of ordinary tunnels, would have been quite inadequate to support the ground and the excessive and constantly-varying pressure occasioned by the river. To meet the special requirements of the case, Sir Isambart Brunel devised a machine, constructed entirely of iron, and so original in its character as to enable him to secure the invention by letters patent. It occupied a space of about 8 feet in advance of the brickwork, and consisted of twelve distinct frames, each about 3 feet in width and 22 feet in height, ranged side by side, like the books on the shelves of a bookcase. Each of these frames was divided vertically into three cells by cast-iron floor-plates, so that the whole shield consisted of 36 cells. The roof and sides were secured by a number of narrow plates of metal, overlapping the portion of the brickwork already built, and entering the ground in advance of the work; while the face of the excavation was secured by timber *polings* so accurately fitted as to leave no aperture whatever through which loose sand or other strata could find their way.

The following brief description of the shield, and the mode of using it, is extracted from Weale's "London Exhibited:"—

"It will at once be seen how admirably the shield was adapted for the duties which it had to perform; the chief of these was, obviously, to support the ground, but a quality equally essential was, the power of being easily advanced or moved forward, as the tunnel progressed. Now, by its division into frames, these two objects were at once attained, for the whole was so contrived that, while six alternate frames were engaged in sustaining the pressure of the ground, the six intermediate frames were relieved entirely from all pressure, and left free to be moved forward without resistance. These, in their turn, then became the pressure-bearers, relieving those which had previously relieved them in a

Fig. 135.



similar manner, and enabling them to be advanced without difficulty.

"'It has been already said that the shield, as first designed by Sir Isambart, bore a considerable resemblance to the worm from which the first idea was derived; but the present shield has much more aptly been compared with a man, to whom, in its general organization, each of these "frames" or divisions bears a resemblance; having legs with both a knee and ankle-joint, with which it alternately steps or walks on in advance of the brick structure; arms, with which it supports and steadies itself, or lends assistance to its neighbours when they require it; and a head, for supporting the superincumbent earth, which can be raised or depressed, or altered in its direction, as circumstances may require.'*

"Fig. 135 affords a view of the three left-hand frames of the shield, as seen from the tunnel, the third frame being shown in section, in order that the mechanism may be more clearly seen; and fig. 136 is a section taken through the same frame, in a line parallel with the direction of the tunnel, or perpendicular to that shown in fig. 135. The sides of the boxes, or frames, are formed by strong castings, A A, securely bolted to the floor-plates, B B, which, as already explained, served to separate every frame into three stories, or boxes. The middle boxes were stiffened, both transversely and longitudinally, by wrought-iron stays or struts, C C and D D; and the shield was strengthened at the back by two wrought-iron straps, E E, which extended from the top to the bottom of both sides of each frame, passing through the intermediate floor-plates. The framings of the upper and lower boxes were sloped away at the back, as shown in fig. 136, to allow more room for the bricklayers in putting in the brickwork. The lower part of the bottom box was secured by a wrought-iron stay or framing, F and G, and the upper

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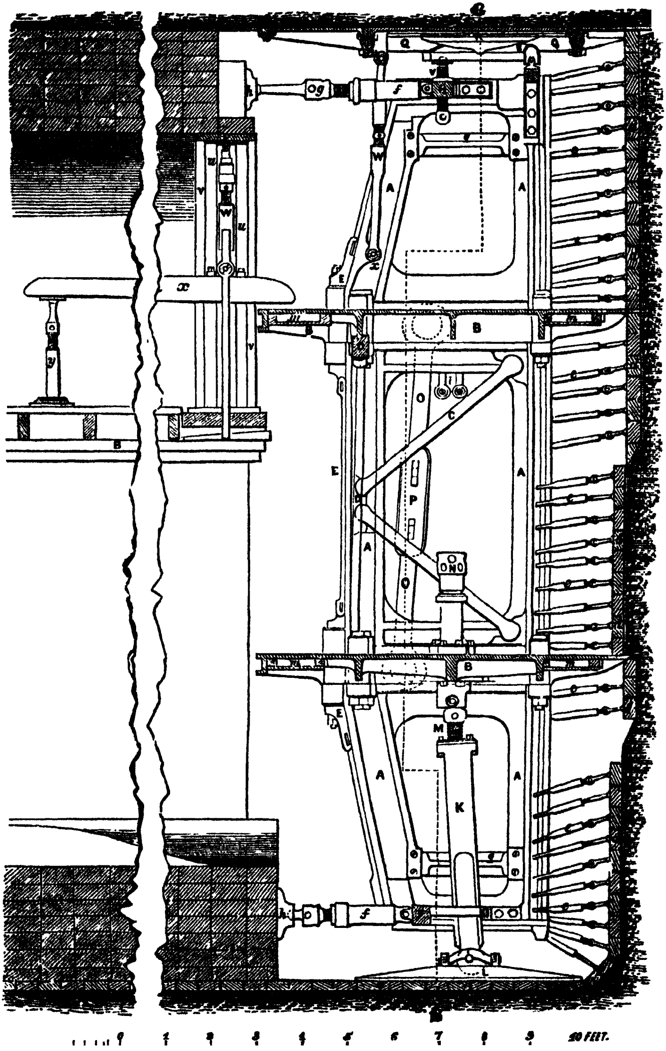
* A Memoir of the Thames Tunnel, in Weale's "Quarterly Papers on Engineering."

Fig. 136.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part of the top box by two similar framings of wrought iron, H and I. Each frame was supported upon two long jack-screws, K K, which, from the duty they had to perform, were termed *legs;* the lower extremities of these jacks rested upon strong wrought-iron plates, L L, termed *shoes*, whose object was, to distribute the weight of the frames, together with the pressure of the superincumbent earth, over a large surface or base; beneath these shoes a flooring of elm planks, 3 inches in thickness, was laid, upon which the brickwork of the tunnel was built, after the ground beneath them had been compressed by the weight of the shield passing over them. The leg was attached to the shoe by a species of ankle-joint, *e*, resembling in principle the method adopted for mounting mariners' compasses, which allowed the shoe to adjust itself readily to any inequality in the ground. At the upper part of the leg was the knee-joint M, about which it turned in the act of stepping forward: the length of the leg could be varied at pleasure, by means of the screw at M, turned by the capstan-head at M, and a second auxiliary one in the middle box, N.

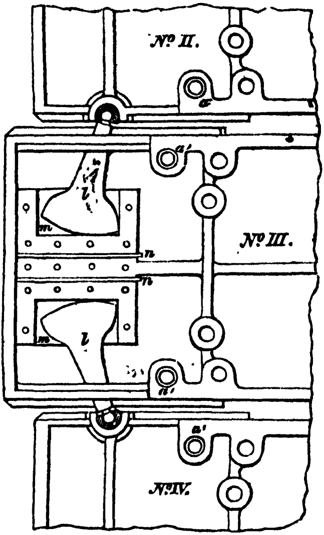
"The frames were also provided with slings, or arms, O, consisting of strong wrought-iron bars, attached at their upper extremities to the floor-plates of the odd-numbered frames, and at their lower extremities to the floor-plates of the even-numbered frames; the attachment consisting in an eye fitting to a circular pin projecting from the side of the floor-plates, so as to allow a freedom of motion about these pins as a center. The upper and lower extremities of the slings consisted of two separate bars of metal connected by two plates or cheeks, one on either side, through which, and the slings themselves, metal keys or wedges passed, by the tightening up or driving back of which, the length of the slings could be increased or diminished at pleasure. The use of these slings was to enable one frame to *derive* support from its neighbour on either side, or, in its turn, to *afford* support to either of its neighbours. Thus, if one of the odd-numbered frames, in which the upper extremity of the slings were attached to the top floor-plates, was required to be supported independently of the legs, it was only requisite to tighten up the wedges and lengthen the slings to raise the frame, and relieve the legs entirely from pressure; the slings, in this case, *pushing up* the frame. While, in the case of an even-numbered frame, by driving back the wedges of the slings on either side, and so lessening their length, the frame would be *drawn up*, and the legs relieved from the office of supporting the weight of the frame.

"The ground over the roof of each frame was supported by two plates of metal, Q Q, the tails of which always overlaid the brickwork, as shown in fig. 136, and the points entered the ground some distance in advance of the boards, by which the front of the shield was secured. These plates of metal (which were technically termed *staves*) were supported upon a cast-iron saddle piece, R, resting upon a swivel, S, which latter, being supported in front upon a kind of joint, U, and at the back upon a jack or strong screw, V, could be raised or lowered at pleasure. This mode of supporting the top staves allowed of their being brought into any position, or having any direction given to them. The tails of the staves were supported by a powerful jack-screw, W.

"The sides of the shield were secured, and the ground supported, by a number of similar staves, Z Z Z, fig. 135, attached to the frames by a sliding bar, passing through a block secured to the sides of the external frames, in such a way as to allow of their direction being altered as circumstances might require. The tails of the side staves overlapped the brickwork of the tunnel in the same manner as the top staves.

"The ground in front of the shield, as we have already mentioned, was supported by small boards of wood, *d d*, termed *poling boards;* each frame had its own set of *polings*, their length corresponding with the width of the frames. These boards were 3 inches in thickness, 6 inches in width, and at each end had small iron plates let in containing a recess, into which the head of a small jack, *e e* (termed the poling screws), fitted; the other end of these screws, resting in recesses formed for them, in the front rail of the cast-iron framing, A A, composing the sides of each box.

Fig. 137.



"The frames of the shield were not in actual contact, a space of nearly 3 inches being maintained between them, to avoid the resistance which would have arisen from the friction of the frames if they had been allowed to rub against each other; and in order to preserve this space, the floor-plates of every odd-numbered frame was provided at each end with a pair of wrought-iron sectors of circles, *l l*, fig. 137 (or, as they were termed, *quadrants*), the heads of which bore against the floor-plates of the even-numbered frames, and the circumference of which worked in the recesses *m m*, formed in the floor-plates of the odd-numbered frames for their reception. The quadrants served only to prevent the frames approaching too close: to obviate their spreading, a powerful tie, formed by two wrought-iron bolts, *t t*, fig. 135, was attached to the two external frames.

"Each frame was supported and maintained in a vertical position by two powerful screws, *f f*, fig. 136, termed the *abutment* screws, one at the top and one at its lower extremity. The heads of these screws rested against iron plates, *h h*, which served to throw the pressure occasioned by the screw over a larger surface of the brickwork. It was by means of these screws that the frames of the shield were advanced*.

"We now pass on to describe the mode in which the excavation was carried on and the shield advanced. We should first state, that every alternate frame of the shield stood three inches in front of the intermediate frames, which latter, when advanced, were moved forward six inches at a time, so as then to stand (in their turn) three inches in advance of the others. Thus, the odd-numbered and even-numbered frames alternately stood in advance of each other. We shall now suppose the odd-numbered frames to be behind, and proceed to detail the method of advancing one of them (No. III.), which will sufficiently explain the process adopted in the case of any one of the rest. Fig. 138 represents a sectional plan of a portion of the frames Nos. II., III., and IV., showing the relative positions of the front rails of those frames, together with their poling boards and the poling screws which supported them. This being the position of things, the first operation is, to remove the poling boards of the frame No. III., one at a time, commencing at the top of the box, and, having carefully excavated or cut away the ground to a depth of three inches, to replace the poling and its two screws; but instead of resting the latter upon their own frame, as they were before, they are now placed against the front rail of the two other frames on either side, as shown in fig. 139; the object of this arrangement being, that the intermediate frame, after all the poling screws have been so removed, shall be left entirely free to be advanced or moved forward without experiencing any resistance from the ground against its poling boards, the whole of which are then temporarily supported by its neighbouring frames. The frame itself is then moved forward the required

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* "It should be mentioned that two shields were employed in the construction of the tunnel. That which we have just described was the second, and contained several improvements which experience had pointed out. They were, however, identical in principle, and in their general mode of action."

Fig. 138.

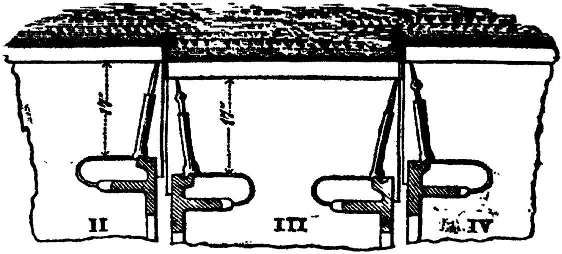


Fig. 139.

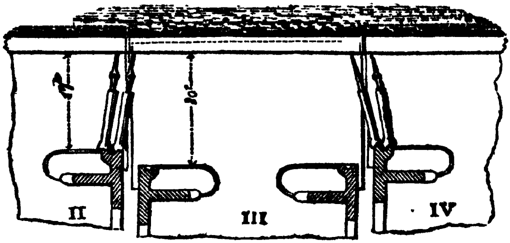


Fig. 140.

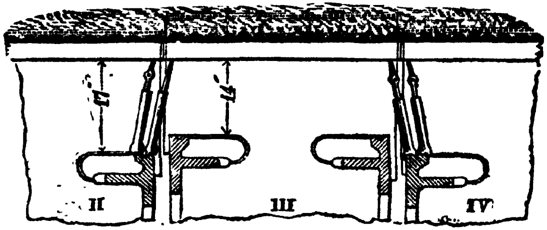
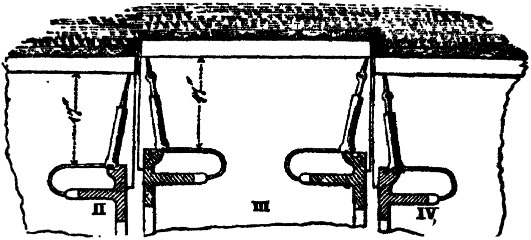


Fig. 141.



distance, or six inches, by means of the large abutment screws, *ff*, fig. 136; the mode of operation being, first, to relieve the legs of the frame from weight by means of the slings, in the manner already explained, then to move forward the two shoes, L L, fig. 135, bringing the legs into the sloping position shown in the fig. 136, after which the frame itself is screwed forward by turning the upper and lower abutment screws simultaneously, until the legs are brought again into a vertical position, and the frame assumes the situation shown in fig. 140, being then three inches in advance of its neighbours, Nos. II. and IV. The poling boards are now again removed, the ground once more excavated to a further depth of three inches, and the boards and poling screws again replaced, the latter being again restored to their own frame, so that they assume the position shown in fig. 141, the frames and polings of the odd-numbered divisions being now three inches in advance of the even-numbered frames, which latter, in their turn, will undergo a similar operation to that above explained.

"In fig. 136 the polings in the upper box are shown as having been worked forward, while in the middle and lower boxes they are represented as being in the act of being worked; in the latter, two polings are shown out at once; this was usually allowed in the lower boxes, the ground in which, being further from the river, was usually more solid than in the upper boxes, and occasionally, when the ground in the latter was unusually good, the miners in those boxes were allowed also to remove two polings at a time.

"When the whole shield had thus been advanced sufficiently to admit of a ring of brickwork being introduced, this was immediately proceeded with, the arches being turned upon a narrow centering or profile, *v*, fig. 136, and being inserted behind the abutment screws, *ff*, one at a time, care being taken that none of the poling screws were resting upon a frame whose abutment screws were not in proper bearing. As the shield advanced, a timber stage on wheels followed it, which afforded ready means of access for the miners and bricklayers to every part of the shield."

CHAPTER IV.

HYDRAULIC ENGINEERING.

BY

G. R. BURNELL, C.E.

HYDRAULIC ENGINEERING.

The subclassification of the branches of Civil Engineering, contained in the Introduction to this work, restricts the application of the above term to subjects connected with drainage, water supply, coast defences and harbours, and improvement of rivers. This classification will be adhered to in the following pages, and only such illustrations of the general scientific principles as are necessary to explain many of the phenomena encountered in the execution of such works, will be introduced.

The term hydrodynamics (from the Greek words ὕδωϱ, *water*, and δύναμις, *force*) comprehends the whole science of watery fluids, under the several branches of *hydrostatics* (from ὕδωϱ and ἵστημι, I place in equilibrium), which treat of their pressure when at rest, and *hydraulics* (from ὕδωϱ and αὐλὴ, a pipe), which treat of their motion. *Pneumatics* (from πνεῦμα, vapour) treat of the pressure and motion of air and other light elastic fluids of a similar nature. The distinction between watery fluids and elastic fluids has been adopted, because, although in fact every description of fluid is compressible and elastic to a greater or less degree, nevertheless, the distinctive difference between the compressibilities of what are called the aqueous and the gaseous fluids, is so remarkable that the verbal distinction may be retained without inconvenience.

Fluids themselves may be defined as bodies whose molecules exist in a state of cohesion so slight, if even in some cases that state exist at all, that the particles are susceptible of being moved in every direction without experiencing any resistance. Different substances, known under the generic name of fluids, have variable degrees of fluidity; and, indeed, it is generally believed at the present day, that the several states of solid, fluid, and gas (or elastic fluid), can be assumed by every substance in nature under the requisite conditions of temperature and pressure. The use of the respective terms must not, then, be considered as implying any necessary or absolute differences in the several substances, but as expressing rather the accidental qualities they possess, under ordinary circumstances. Water itself is a remarkable illustration of the faculty of any body to assume the three different states; in hydraulic engineering, however, our attention will be principally directed to its consideration under the fluid form.

Gases possess, in addition to the extreme mobility of their particles, the peculiar property of the existence of a species of repulsion between these particles, in consequence of which they dilate, or increase in volume, unless confined by pressure. Liquids, then, are further defined to be fluids having no tendency to increase in volume; and gases, to be fluids having such a tendency. Some gases, such as atmospheric air, may, for our purposes, be considered to be permanent gases; whilst others are so frequently condensed by the operation of ordinary natural causes, that it has been proposed still further to classify the gaseous fluids into the subdivisions of *vapours*, or those condensing easily into liquids, and *gases*, or those retaining permanently their peculiar condition.

1. Hydrostatics, or the Science of Water at Rest.

When water is perfectly pure and at its maximum density, its weight may be taken at 62 lbs. 5 oz. avoirdupois per cubic foot; and its specific gravity is usually considered to be represented by that quantity. Three causes, however, may contribute to modify this weight. The first, and the most important, is the temperature of the water; for it is well known that heat is able to dilate all substances, and thus to diminish their density or specific gravity. The second modifying cause consists in the presence of the earthy or mineral salts which may exist in combination with the water. The third consists in the loss of weight which occurs when that property is ascertained, whilst the water is surrounded by atmospheric pressure: the influence of this modifying cause is susceptible of, perhaps, greater variation than the others, compared with the amount of influence it exercises.

The effect of heat upon the specific gravity of water has been ascertained by a series of careful experiments to be as represented in the annexed table, in which the specific gravity of water at 39°·20 Fahrenheit is taken as unity, for the purpose of making the table correspond with those adopted by scientific authorities abroad. Below 39·20 the density, instead of increasing, diminishes, slowly at first, but with greater rapidity as the point of congelation is approached; and the weight of ice itself does not exceed 0·930.

Temperature.	Weight.
39·20	1·00000
42·80	0·99995
46·40	0·99987
50·00	0·99972
53·60	0·99954
59·00	0·99914
68·00	0·99824
77·00	0·99709
86·00	0·99573
122·00	0·98758
212·00	0·95670

The effect of saline matters in combination may, under most circumstances, when fresh water is considered, be omitted; distilled water, usually taken as the type, not differing from river waters more than from $\frac{1}{10000}$ to $\frac{2}{10000}$. Observations made upon the waters of the Garonne indicated an average specific gravity of 1·000149; and similar observations upon those of the Seine gave, as nearly as possible, the same results. The specific gravity of sea-water is, however, much greater; it is 1·028, and a cubic foot weighs about 64 lbs. 2·5 oz.

The loss of weight arising from the displacement of the air by the water, may vary from $\frac{10}{10000}$ to $\frac{13}{10000}$ of the latter.

The effects of mechanical pressure upon the specific gravity of water are very inconsiderable, in a practical point of view. For many years, indeed, water was considered incompressible.

Later experiments have, however, demonstrated that it may be so compressed as really to diminish in volume, although to a very small extent. Under the pressure of one atmosphere the diminution is not above 0·000046 of the original volume; but as in ordinary calculations it is not necessary to reason upon depths of water so great as to make the effect of compression by the superincumbent fluid sensible, this consideration may be left out of question. And as the average specific gravity of water in our latitudes, at ordinary temperatures and under ordinary circumstances, only varies within the limits of 0·9984 and 0·999, the normal specific gravity being unity, it rarely happens that it is necessary to take any of these modifying causes into account.

The other physical properties of water, such as its porosity, elasticity, and cohesion, although of great interest to the philosopher, are of little importance to the engineer, whose operations are generally conducted upon too broad a scale to call for the examination of causes possessing a degree of influence which to him would be inappreciable.

In all investigations of the laws of equilibrium of water, it is admitted, in addition to the property already stated, that although under very great pressures it diminishes in volume, it may, for all practical purposes, be considered incompressible; that its molecules possess perfect freedom to move in any direction; and that it communicates equally throughout its mass the pressure exercised upon any point of its surface. It is also allowed, that any molecule of a definite liquid mass supports in every direction a pressure equal to the weight of a vertical column of similar molecules, starting from it and continuing to the surface of the liquid. From this last-named law some very remarkable consequences follow.

1. Every layer, so to speak, of a homogeneous liquid mass, supports an equal pressure on every point of its surface.

2. The sum of the pressures supported by a horizontal layer is equal to the weight of a liquid cylinder whose base

is the surface of the layer, and whose height is the distance from this layer to the surface of the fluid.

3. The pressure exercised upon any portion of a containing surface, whether horizontal, vertical, or inclined, is perpendicular to this surface; for the pressure must be destroyed by its resistance, and the surface of a body can only resist perpendicularly to its direction; and this pressure is equal to the weight of a liquid cylinder having for its base the portion of the surface under consideration, and for its height the distance to the surface of the liquid.

4. The pressures being equal upon all the points of the lower horizontal surface of a vase containing the fluid, the total pressure it supports is equal to that of the liquid cylinder whose base might be that surface, and whose height might be the distance between it and the upper surface of the fluid; so that this pressure would remain the same whatever be the form of the vase, provided that the area of the bottom and the height of the liquid did not vary.

The above laws furnish the means of calculating the resistances which vases containing fluids ought to offer, so as not to yield to the pressures exercised upon them. When a vase with a circular cylindrical section, or vertically conical, contains water, each horizontal ring is pressed on all its points by the column of water above it. Now, as in the case when all the points of a circle are equally pressed in an outward direction, the effect of this pressure to force out the circle at any point of its circumference is proportional to the intensity of the force acting upon each point, and to the radius of the circles, it follows, that the effort of a fluid to burst a circular vase, is proportional to the distance of the ring under consideration from the surface, and to the radius of the vase. If it were then desired to give the vase a thickness able to resist the pressure, or if it were only desired that the strength should exceed the effort in an equal proportion for the whole depth, it would follow that the thickness should be increased in proportion to the height of the fluid above the point in question.

When the shape of the vase, instead of being cylindrical, augments in diameter towards the bottom, the forces tending to burst the vase augmenting, not only with the depth but also with the diameter, require that the increased thickness of the lower portions exceed that of the higher in a greater degree than if the vase were cylindrical. If, therefore, in a large vase a uniform thickness be given sufficient to resist the thrust at the bottom, it will be far in excess of what is required at the top.

The tangential traction exercised by a fluid upon the sides of a vase containing it, may be represented algebraically by the expression $\mathrm{R}h$, in which $\mathrm{R} =$ the radius, and $h =$ the pressure supported by the surface of the ring. The thickness necessary to resist this traction must, therefore, be such as to present a resistance greater than the effort $\mathrm{R}h$ under any circumstances, whether arising from an accidental increase of pressure, or from a diminution of the resistance of the materials by oxidation or any other cause.

It is often necessary not only to ascertain the total value of the pressure exercised against any definite portion of the surface of a vessel, but also the point of application of the resultant of the pressures producing it; for this would be the point to which it would be necessary to oppose a force perpendicular to the surface, and equal to the supposed total value, in order to equilibrate it. This point is called the center of pressure.

Now it must be evident, that if the pressures exercised upon the different portions of the surface were coequal, the center of pressure would coincide with the center of gravity of the surface; but as the pressures vary with the distance from the surface of the fluid, the center of pressure is always below the center of gravity.

It is found that the center of pressure against a rectangular surface whose upper side coincides with the surface of the water, is to be found upon the lines joining the middles of the horizontal bases, at a distance of two-thirds of its height from the top; or, calling x the center of pressure, l the height of the rectangle measured on the line joining the middle points of its horizontal bases, $x = \frac{2}{3} l$. The center of pressure of a triangle, whose base is horizontal and upon the water line, is in the middle of the line joining the summit with the middle of the horizontal base, or $x = \frac{l}{2}$. The center of pressure of a triangle whose summit is at the water line, and whose base is horizontal and at the lower level, is on the line joining the summit to the middle of the base, and at three-fourths of the distance from that summit, or $x = \frac{3l}{4}$.

The principal application of these principles is to be found in calculating the supports required for large vessels containing liquids, which frequently come within the sphere of an engineer's professional duties.

Should the surface of the bottom of the containing vessel not be horizontal, as it has hitherto been supposed to be, the pressure exercised upon it will be ascertained by multiplying the area into the depth of the center of gravity from the surface of the fluid. It must be borne in mind, in all calculations of this description, that, whatever be the pressure upon the sides of any vessel, ascertained by the laws given above, the pressure upon the bottom is equal to the weight of the whole fluid acting upon it vertically. In close vases also, if any pressure be applied to the surface of the fluid, every portion of the containing sides and bottom would be affected by it. These laws are of the utmost importance in fixing the dimensions of constructions intended to hold or to resist the action of large bodies of water, such as reservoirs, cofferdams, sluices, &c.

It may be convenient to remember, that the pressure of fresh water is always about 13 lbs. upon every square inch of horizontal surface, at the depth of 30 feet, whatever the form or position of the sides may be; and so in proportion for greater or less depths of water.

If still water be contained in vases communicating freely with one another by tubes or passages of considerable dimension, the equilibrium of pressure can only exist when it stands at the same level in both of them; and equally, if several vessels be employed, the condition of equilibrium will be that the same level exist in all of them; or, in other words, the pressure arising from the weight of a liquid being proportional to its depth, and being transmitted equally in every direction, the surface must always be at the same level in all vessels communicating freely with one another. It is upon the law of equilibrium of liquids in communicating vessels, that the principles of the connection of reservoirs are founded.

But the law in question only holds good when the communication is of a considerable sectional area, and the water is retained in the supposed vessels: when the passage is very small, the equilibrium becomes affected by a new power, known as the capillary action. This may be observed whenever a body or substance is partially immersed in water, for the latter either rises or falls round it, and, according as the body may be raised or depressed, the water assumes a concave or convex form. There are few substances in nature which do not possess the power of producing this phenomenon: polished steel is, however, one of the apparent exceptions; when plunged into water, that liquid retains its level at the point of contact with the surface of the steel.

The energy of capillary action depends very much upon the form, disposition, and distance apart of the sides of the tubes which excite it. In minute cylindrical tubes it is greater than in such as are prismatic, and in both it is greater than between parallel plates. The elevation or depression in cylindrical tubes is in the inverse ratio to the diameter; in prismatic tubes, it is in the inverse ratio of the wet contour of a horizontal section; in the case of parallel plates, it is in the inverse ratio of their distance asunder. The surface of the fluid between the plates is perceptibly a demi-cylinder, with a semicircular base whose axis is horizontal; in a cylindrical tube the surface is that of a demi-sphere, whose diameter is equal to that of the tube.

Minute as the effects of capillary action may appear to a casual observer, they are of the greatest importance in many branches of practical science, and merit more attention than they usually receive from engineers. They have a very marked influence upon the durability of building materials, for it is worthy of observation, that the latter always begin to yield at the extremities of the zones of capillary action. In the cases of sea or river walls, the capillarity of the earthwork backing tends to augment its weight to a very serious extent; indeed, on account of this action, the earth in all such positions must always be considered to be a semi-fluid, denser than the earth itself in its dry or normal condition. Many failures have occurred from the neglect of this apparently self-evident law.

In order that a body may remain in equilibrium in the midst of a liquid, it is necessary—1, that its weight be equal to that of the fluid displaced; 2, that the center of gravity of the body and of the displaced fluid be upon the same vertical line; and 3, that the center of gravity of the body be as low as possible. The two first conditions evidently result from this, that the weight of the body and the pressure of the fluid are two parallel forces, which can only destroy one another when they are equal and directed in the same line; the stability resulting from the third condition follows from the principle that the center of gravity of a body always has a tendency to assume the lowest position.

When a body floats upon any liquid, the conditions of equilibrium are virtually the same as when it is entirely submerged; for the body tends to sink by its weight, and to rise by the pressure which the fluid exercises upon the portion of its surface submerged, a pressure which is evidently equal to the weight of the fluid displaced, and applied to its center of gravity. It follows from this, that in order that a body may float upon the surface of a liquid, its weight must be less than that of an equal volume of the latter. Should the body be in a state of equilibrium, the weight of the liquid displaced is equal to the total weight of the body; and the center of gravity of the latter, as well as that of the liquid displaced, are in the same vertical line. The equilibrium will only be stable when the center of gravity of the body is lower than that of the water displaced.

The property by which bodies displace a quantity of water equal to their volume when their specific gravity exceeds that of the water itself, is usefully applied, if that specific gravity be known, to ascertain their precise weights. All that it is necessary to do in such cases is, to multiply the weight of the cubical contents of the volume of water displaced by the specific gravity of the material, and the result will be the weight of the body in question.

Specific gravity means the ratio of the weights of certain bulks of the substances considered to equal bulks of some other substance with which they are compared. Water being a substance but little exposed to variation, and with which most others can be readily compared, has been adopted as the standard. The specific gravity of gases is, however, ascertained by adopting the weight of dry atmospheric air as the standard. It follows that the specific gravity of a solid, or liquid, is obtained by dividing the weight of a portion of the substance by the weight of an equal bulk of water; and similarly, the specific gravity of a gas is obtained by dividing the weight of a given bulk of it by that of an equal volume of air. A table of specific gravities is attached; but it is particularly to be observed in practice, that the weights of equal volumes of two substances depend upon the weight of a definite unit of the term of comparison previously ascertained.

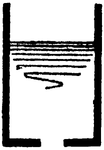
For instance, if the unit of weight be a cubic inch of water, that of the substance to be compared with it will be ascertained by multiplying the number of cubic inches it may contain by the weight of a cubic inch of water, and by the tabular number.

TABLE OF SPECIFIC GRAVITY OF BODIES (HUTTON AND CARR).

Platina, pure	(Hutton)	23·400	Clay	(Hutton)	2·160
Standard gold	„	18·888	Brick	„	2·000
Standard silver	„	10·535	Common earth	„	1·984
Cast lead	„	11·325	Sand	„	1·520
Quicksilver	„	13·600	Coal	„	1·250
Cast copper	„	8·788	Box wood	„	1·030
Gun metal	„	8·784	Sea-water	„	1·030
Cast brass	(Carr)	8·395	Common water	„	1·000
Iron, cast	„	7·207	Ash	„	0·800
Iron, bar	„	7·788	Maple	„	0·755
Steel, hard	„	7·816	Oak	„	0·925
Tin	„	7·291	Elm	„	0·600
Zinc	„	7·196	Fir	„	0·550
Glass, flint	„	3·329			
Glass, white	„	2·892	Sulphurous acid gas		2·265
Glass, bottle	„	2·732	Carbonic acid gas		1·500
Serpentine	„	2·988	Nitrous gas		1·194
Basalt	„	2·864	Hepatic gas		1·106
Marble	„	2·741	Oxygen gas		1·103
Granite	„	2·654	Nitrogen gas		0·985
Porphyry	„	2·765	Ammoniacal gas		0·600
Flint	(Hutton)	2·570	Hydrogen		0·084
Common stones	„	2·520	Atmospheric air		1·000

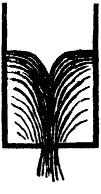
HYDRAULICS, OR THE SCIENCE OF FLUIDS IN MOVEMENT.

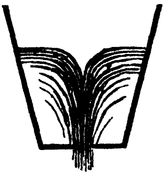
We have seen that when a fluid is contained in a vase of any form, it exercises, in consequence of its gravity, pressures upon every portion of its surface perpendicular thereto. If, then, the vase be perforated, the liquid will escape with a certain velocity; and at the same time certain movements will take place in it whilst in the interior of the vase, which we will proceed to notice.

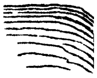


When a small hole is made in the bottom of a vase the molecules move vertically to within a short distance of the orifice, supposing that the top surface be exposed to the direct influence of the atmosphere, but the other molecules flow towards the orifice from every direction. If the orifice be on the side of the vase, the molecules, both above and below, move towards it; so that in every case their movement is towards the orifice from every direction, and as the same quantity of liquid must pass through the same space in the same time, if the pressure be uniform, the mean velocity of each such quantity must be in the inverse ratio of the surface it occupies in the vase.

The upper surface of the liquid in the vase is not always terminated by a horizontal plane. When the jet escapes vertically by an orifice in the bottom, and the level has nearly fallen to that of the orifice, the liquid withdraws from the line of its axis and assumes the shape of a funnel, whose apex is in the center of the orifice. If the liquid had a rotary movement in the vase, or if the shape of the latter were of that description, the funnel formed by the upper surface of the fluid would be developed at an earlier period. If the orifice were lateral, the funnel would not be formed, but the surface of the liquid would be depressed immediately above the orifice, as in the accompanying figures.





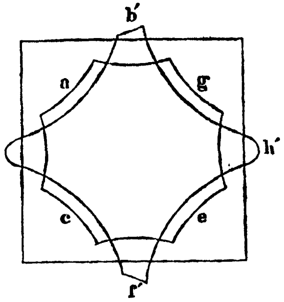


These movements depend upon the form of the vases, the height of the liquid, and the position and dimension of the orifice. Hitherto it has not been found possible to bring them under any general laws.

The liquid vein escaping from an orifice takes the form of a prism whose base would be the orifice itself, but which diminishes gradually until it reaches a distance from the latter equal to about half its diameter, where its thickness is not more than 0·6 or 0·7 of the orifice. This diminution is known by the designation of *the contraction of the fluid vein;* and it takes place in whatever direction the water may flow. When, however, the jet takes place vertically downwards, the prism contracts for a greater distance, because the velocity of each horizontal layer increases in proportion to the space fallen through, and therefore the distance between any two layers must also increase. For the same reason, when the jet takes an upward direction the prism enlarges after the contracted vein, because the velocity diminishes. In all cases, beyond a certain limit, the resistance of the air divides the jet into drops of greater or less volume. In vacuo, the jet, if not vertical, would describe a parabolic curve in falling, like solid bodies.

The cause of the contraction of the fluid vein does not appear to arise from any contraction of the fluid itself, but it lies in the fact that the molecules leave the orifice with different parallel velocities. Those which pass through the center of the orifice have an initial velocity greater than the others, and necessarily the column must diminish; in a short time, however, the velocity becomes equalized throughout the column, and it would remain constant if the pressure and the resistance of the air did not interfere with it. The inequality in the velocity of the molecules is caused by the various inclinations under which they approach the orifice, and by the friction against the sides of the latter.

When the jet is vertical and downwards, and the liquid has a rotary movement, a species of funnel is formed in the interior of the vase, and the liquid leaving it assumes a similar form, but its apex is in precisely the opposite direction to that of the funnel in the interior. If the sides of the orifice be not perfectly even, and the liquid in the interior be impressed with a rotary movement, the liquid in escaping often takes the form of a spiral column.



When the orifice is polygonal, or of any other than a circular form, the outline of the fluid vein is more complicated, but the results are not affected. The different parts of the orifice not being symmetrical, the vein does not retain the form which it had on leaving the orifice, but it changes continually as it increases in distance. Immediately after leaving the orifice the faces corresponding to the rectilinear sides become hollow, and the concavity increases; the edges corresponding to the angles are splayed off, and finally they disappear entirely. Thus MM. Poncelet and Lesbros ascertained that the form of a vein leaving an orifice perfectly square, measuring 8 inches on each side, at a distance of 6 inches presented the section $a\ c\ e\ g$; and at 1 foot, the section became $b'\ d'\ f'\ h'$. This last was its smallest section, and its area was 0·562 to 1 of the orifice, whilst the effective quantity discharged was 0·605 to 1 of that indicated by theory. The head of water above the orifice was 5 feet 7 inches.

In this case the vein seems to have made the eighth of a revolution upon its axis; and the researches of Bidone show that many other interesting phenomena occur in the course of a jet. The reader is referred to his very interesting work, "Expériences sur la Forme et la Direction des Veines et Courants d'Eau lancés par diverses Ouvertures," for more complete information on the subject. It may suffice to state, that if the jet be of any length, a series of contractions and expansions takes place in it, accompanied by changes in its transverse section when the form of the orifice is pentagonal.

The velocity with which a fluid leaves an orifice is, at the commencement, imperceptible; it increases for a certain period, after which it remains constant, if the level of the fluid continue the same in the vase, or it decreases if the level be lowered. Whatever be the form of the opening, or whatever be its size compared with the transverse section of the vase, so long as the water in the latter remains still, the constant velocity with which the fluid will escape will follow the same law.

When the orifice is made in a thin plate, or when the thickness of the side of the vase does not exceed the smallest dimension of the orifice, and is, at a maximum, only from 2 to 2¼ inches, the rate of flow, when no initial velocity exists, is accurately expressed by Toricelli—

$$V = \sqrt{2gh}, \text{ from which } h = \frac{V^2}{2g}.$$

V = the theoretical velocity; the real velocity is found to be from $V - 0{\cdot}1\,V$ to $V - 0{\cdot}2\,V$; the diminution in the velocity being attributable to the friction of the water against the sides of the orifice, and to the resistance of the air.

In the above formula h = the height of the liquid in the vase above the center of gravity of the orifice.

g = the acceleration of motion due to gravity in a second; it is in London considered to be $32\frac{1}{6}$ feet.

The velocity in this case is that which a heavy body would acquire in falling in vacuo through h; and as the velocity is proportional to the square root of the height of the liquid above the center of gravity of the orifice, if the height be quadrupled the velocity will only be doubled.

When the liquid flows through an orifice whose length is 1½ times its smallest transverse dimension at a minimum, or when an ajutage is employed whose length is equal to two or three times the smallest dimension of the orifice, the formulæ become $V' = 0{\cdot}82\ V = 0{\cdot}82\ \sqrt{2gh}$; V' being the real velocity with which the water flows, and the other notation as before.

The velocity is modified if the two faces of the orifice be under water, and it becomes $V = \sqrt{2g(h - h')}$, in which h' = the height of water in the second recipient, and $(h - h')$ = the difference of levels between the water in the two vessels, retaining the preceding values of V, g, and h. If the discharging vessel be subject to any pressure, the formula becomes $V = \sqrt{2g(h + h')}$, in which h' = the pressure exercised, expressed in the height of a column of the liquid.

If we leave out of account the diminution of the velocity and the contraction of the fluid vein near the orifice, the theoretical discharge would be $Q = S V$; in which Q = the quantity discharged per second, S = the sectional area of the orifice, and $V = \sqrt{2gh}$. But the quantity which really flows from any orifice differs considerably from that indicated by theory, and it is usually expressed by the formula $Q = K S V$, in which the new term K = the coefficient of discharge, or the ratio of the real to the effective quantity flowing from the orifice. The value of this coefficient depends upon the pressure upon the orifice, its form, and its position in the sides of the vase.

The greatest contraction takes place when the orifice is removed from the bottom and the sides of the vase by a distance at least equal to 1 or 1½ times its smallest dimension, under which circumstances the contraction takes places all round. But, if the sides of the opening be in the prolongation of the sides of the vase, the coefficient of contraction requires to be multiplied by 1·035, in the case when the prolongation exists on one side; by 1·072 when it exists on two sides; and by 1·125 when it exists on three sides. MM. Poncelet and Lesbros have determined the values of the coefficient of discharge for rectangular orifices with the greatest contraction, and they are presented in the table No. 1 of Appendix, in which the dimensions are given in English feet and inches. They are equally applicable for other forms of orifice, without any inward projection, provided that the smallest dimension be that of the height of the table; and they are equally applicable when the discharge takes place in the open air or under water. It is important, however, to observe that, if all other conditions remain the same, the contraction diminishes in proportion to the thickness of the orifice, for when the latter is considerable it acts to a certain extent as an ajutage; and that when the sides of the vessel are convex outwards the discharge is increased, whilst, on the contrary, it is diminished if they be convex inwards.

In the sluices of lock gates, the sills of which are generally close upon the floor of the lock chambers, the coefficient of discharge is always 0·625, whether the sluice work in water or not. Formerly it was usual to adopt a coefficient of 0·55 when two sluices were used, but more recent experiments appear to show that the real coefficient should be, as in the last case, 0·625. With inclined sluices, such as are used in Poncelet's wheels, the lower and side faces of which are in the prolongation of the reservoir, the coefficient is 0·74 if the upper face have an inclination of 1 to 2; and 0·80 if the inclination be 1 to 1; the sectional area being obtained from the vertical height, not from that measured perpendicularly to the opening.

The effective discharge of weirs, or overflows, is stated by Poncelet to be represented by the formula

$$Q = K L H \sqrt{2 g H}.$$

Q = the effective quantity falling over.

K = the coefficient of discharge; which generally = 0·405, according to that authority.

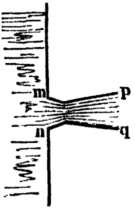
L = the width of the overflow.

H = the height of the water above the sill of the overflow: this height is to be ascertained at a point where the level of the water is not affected, or usually at about from 4 to 8 feet above the overflow.

In table 2 are given the various coefficients for different values of H observed by MM. Poncelet and Lesbros. And it further appears from their investigations, that the usual coefficient 0·405 becomes 0·42 when the overflow is of the same width as the leading channel, and when the depth of the latter corresponds nearly with H. If we call the thickness of the sheet of water falling over, measured upon the inner edge of the overflow, h, it will be found that H = 1·178 h, when the overflow is $\frac{4}{5}$ths of the width of the reservoir; and that H = 1·25 h, when the two widths are equal.

When cylindrical tubes are added to an orifice in any vase or reservoir, the discharge through the former is greater than that through the latter, supposing the conditions of the head and of the sectional area to remain the same. This effect will not, however, be produced unless the water fill the orifice of discharge, which will take place when the length of the tube is three or four times its diameter; but, on the contrary, will not take place when the length of the tube is smaller than that of the contracted vein. If the ajutage be cylindrical, and the water fill it entirely, the increase in the discharge, when the length of the ajutage does not exceed four times its diameter, is in the proportion of 1·33 to 1·00.

The effective discharge may be still further increased by making the ajutage cylindrical, and of the form represented by the accompanying figure, provided the liquid fill it entirely. This ajutage is composed of two portions of cones upon the same horizontal axis; the first has the form of the contracted vein, the length of the second is three times that of the first, and the opening, $m\ n$, of the first, is $\frac{7}{8}$ths of $p\ q$ of the second. The effective discharge through an ajutage of this description is in the proportion of 3 to 2 of that which would take place through an orifice in a thin plate.



In the case of the discharge of water through long pipes, if the latter have a general fall, the velocity of flow is increased by the effect of gravitation; and as the liquid column is prevented from changing its form by the adherence to the sides of the pipes, and by the resistance of the air, the lower filaments of the liquid transmit a portion of their velocity to the upper ones, and establish a general uniform velocity, which increases in proportion to the length of the pipe up to a certain point, beyond which the friction stops its increase. In horizontal pipes this friction repeated upon a great length tends continually to diminish the velocity; so that if the length be considerable in comparison with the initial velocity, the liquid will hardly flow at all.

Eytelwein states that, in consequence of the existence of this friction, the head of water producing motion in a pipe may be divided into two parts, one of which serves to generate the velocity, and the other to overcome the friction. This portion must, therefore, be directly as the length of the pipe, and the circumference of the section (or as the diameter of the pipe), and inversely as the contents of the section, or as the square of the diameter. This subject will be found treated more in detail in the subsequent chapter of this work devoted to the consideration of the water supply of towns, on account of its more intimate connection with that branch of hydraulic engineering.

It appears from numerous experiments, that the rate of flow in pipes is not sensibly modified by the nature of the substance of which they are formed, and that it depends alone upon the length and diameter. The resistance increases in proportion to the square of the velocity, the length of the pipe, and in the inverse ratio of the diameter. Any curves or deviations from the straight direction, whether in a vertical or horizontal direction, diminish the velocity considerably. If they cause a severe shock, it is even possible that they may so effectually disengage the air in suspension in the water as to entirely interrupt the flow.

In capillary tubes, as might naturally be expected, the velocity is more affected than in those whose diameter is considerable, because the friction only affects those portions of the liquid which touch the sides of the tubes, and it must, therefore, be the greatest when these are in immediate proximity to the axis.

Bernouilli observed that when liquids flowed in pipes, the pressure they exercised against the sides of the latter was always less than the pressure they would exercise if they were in a state of rest. The effective pressure is stated by him to be equal to the height of the liquid at the point observed, diminished by that of the liquid able to produce the velocity actually existing at that point. From this it would follow that the pressure will always be in the inverse ratio of the velocity, and that it would be annihilated if the latter were really that due to the head over the point of observation. This law has been verified by a sufficient number of experiments to be received as correct.

In channels, the fact of the upper sides being open modifies to a serious extent the conditions of the flow of water; and it is found that, whatever be its section, if a uniform velocity be once established, it will deliver the same quantity of water at one end which it receives at the other; consequently, in any transverse section of the channel the same quantity of water must pass in the same period of time. It follows from this, that the velocity of the current must increase in proportion to the diminution of the channel; and, on the other hand, it must diminish in proportion to the increase of the latter. As the rate of flow is produced by the action of gravitation, it must increase with the inclination; and in order to obtain an equable discharge, the several conditions of the dimensions and inclination must co-ordinate. In a channel with a uniform inclination and section, however, the rate of flow is uniform, because the friction of the sides destroys the increase of velocity which would otherwise be produced by gravitation. From this friction upon the sides it also follows that the velocity is not equal for all the molecules; those which are immediately in contact with them are retarded in their flow, and in their turn they retard the molecules immediately around them. Of course the maximum velocity exists at the surface of the current.

From the experiments of Dubuat it appears that the mean velocity of any stream in an open channel, represented by v, was equal to a coefficient of the maximum velocity varying between 0·76 and 0·891; the maximum velocity being represented by V. It is usual in practice, therefore, for surface velocities varying between 8 inches to 5 feet, to consider that $v = \frac{4}{5} V$, or $V = 1{\cdot}25\, v$. But in large rivers these formulæ give velocities in excess of those actually found to exist; for it has been ascertained by actual observation, that in the Seine $v = 0{\cdot}62\, V$; and M. de Rancourt found that in the Neva $v = 0{\cdot}75\, V$.

The German engineers who have examined this subject have found that the mean velocity of all the fluid veins met by the same vertical line bore a proportion to the velocity at the highest point on that line, varying from 0·88 to 0·92. From the experiments made by M. Defontaine upon the Rhine, this ratio would appear to be 0·88 in that river.

Dubuat concluded, from his observations, that the velocity at the bottom of a channel, calling it U, was $U = 2v - V$, keeping the same significations of v and V; and from this, if $V = 1{\cdot}25\, v$, $U = 0{\cdot}75\, v$, or $v = 1{\cdot}33\, U$. In the formation of any watercourse, then, U must be taken of such a velocity as not to allow the materials of the bed to be carried away; and the other dimensions will be ascertained from the following formulæ for channels of a uniform inclination and constant section.

In this case, calling Q the discharge, S the sectional area, and v the mean velocity, we have $Q = S v$; from which also we have $v = \frac{Q}{S}$. The inclination will be ascertained, calling it I, by the formula $I = \frac{P}{S}(av + bv^2)$ according to De Prony. In this, P = the wet contour, S the sectional area, and a and b numerical coefficients which he makes respectively 0·0000444 and 0·000309. Eytelwein was induced to change these coefficients from some other observations, and to make $a = 0\cdot000024$, and $b = 0\cdot000365$. But it would appear that Eytelwein's values of a and b are only correct for large rivers; whilst for channels whose sectional area would be about 10 yards superficial, De Prony's are more correct.

If we call the quotient of the transverse section of the watercourse S, by the wet contour P, the mean radius, and represent it by R, we have $R = \frac{S}{P}$; and the formula of De Prony gives us*, replacing a and b, by his values,—

$$RI = 0\cdot0000444\,v + 0\cdot000309\,v^2,$$

from which we obtain—

$$v = \sqrt{0\cdot005163 + 3233\cdot428\,RI} - 0\cdot07185, \text{ or nearly;}$$

$$v = 56\cdot86\,\sqrt{RI} - 0\cdot072.$$

From these formulæ it will be easy to ascertain the value of v, if I and R be known, or to ascertain the inclination, I, necessary to obtain a velocity such that $v = \frac{Q}{S}$. The value of R depends upon that of the section S, and the form of this section, which, generally speaking, is regulated by local considerations. If the channel be in wood or in masonry, it is preferable to make the sides vertical, and the width equal to twice the depth of the water, so as to render the wet contour, and consequently the surface producing friction, as small as possible. For canals in earthwork the slopes vary, and the width ranges from four to six times the depth of the water.

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* De Prony's values are given in metres; and in Playfair's "Outlines of Natural Philosophy" they will be found translated into English; but if the yard, divided decimally, be used as the unity instead of the metre, no very serious error can arise from the application of the values given by the first-named author. It may perhaps not be out of place to express regret that the very perfect and beautiful system of weights and measures of France are not universally adopted, instead of the numerous absurd and arbitrary measures we find to prevail in other countries.

De Prony's formula $v = 56{\cdot}85 \sqrt{R\,I} - 0{\cdot}72$ will serve not only to ascertain the discharge of a channel of a uniform inclination and constant section, but also to gauge any stream, provided a length of about 500 yards can be found upon it where those conditions may be fulfilled. A cross section will give the area and the wet contour of the stream, and dividing the former by the latter the mean radius, R, will be found; a longitudinal section will give the total inclination of the regular portion of the stream, and this inclination, divided by the developed length of the axis, will give the partial inclination in each unity of length. If the section of the stream should not be constant, which is frequently the case in natural channels, a certain number of cross sections must be taken in the portion where the stream is most regular, from which an average must be obtained. The wet contour, and the mean radius, R, are also to be found by taking the averages derived from the series of cross sections. The inclination is then to be ascertained from the mean velocity, v, and the discharge by the ordinary formulæ. Should it happen, however, that the stream is divided into two portions, one of which is very deep, and comparatively speaking narrow, whilst the other is shallow and broad, it would be preferable to consider the stream as divided into two separate branches, and to calculate the discharge of each of them.

It is possible, also, to ascertain the volume of a river by determining the maximum velocity at the surface, observing all the precautions necessary to insure a correct mean result. The transverse section must also be ascertained from the average of a sufficient number of profiles, and the discharge will be obtained by multiplying the sectional area by the mean velocity, which we have seen to be 0·8 V. It is essential that the floats be thrown into the stream a little above the points of observation, in order that they may have the velocity of the latter during their passage.

The preceding observations apply when the volume of water passing an orifice, or through any given portion of the channel of a stream, is such as to maintain a constant head. If, however, the discharge be greater than the supply, the level of the water above will lower, and the head necessarily be diminished. The value of H in such cases will have to be modified, so as to express the effective average head influencing the discharge during the entire operation. It has also been assumed that the discharge takes place in the open air, and without any resistance on the under side; but in the case of one reservoir pouring its waters into another, not only does H require to be modified, but a new term requires to be introduced to express the variable resistance of the water on the under side as it rises above the orifice of communication.

Morin gives a rule to ascertain the discharge when a variable head exists over the center of an orifice, which may be stated as follows. A vertical rule is placed in the reservoir, upon which are to be measured the levels corresponding to equal intervals of time; for ordinary purposes five observations will suffice. Then, calling L the width of the orifice, E its height, m the coefficient of discharge, the arithmetical mean between the values corresponding with the greatest and least heads observed, h_1, h_2, h_3, h_4, h_5; the levels at the different intervals of time t; the quantity discharged during the total period, or $4t$, will be

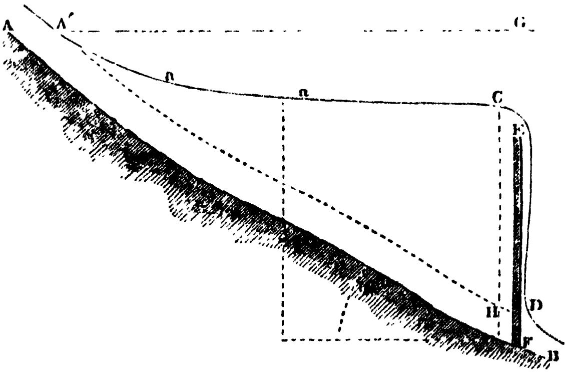
$$Q = 1{\cdot}476\, m\, \mathrm{LE}\, t\, [\sqrt{h_1} + \sqrt{h_5} + 4\,(\sqrt{h_2} + \sqrt{h_4}) + 2\sqrt{h_3}].$$

The formula becomes, when the flow over a weir is considered,

$$Q=0{\cdot}598\,\mathrm{L}t[h_1\sqrt{h_1}+h_5\sqrt{h_5}+4(h_2\sqrt{h_2}+h_4\sqrt{h_4})+2h_3\sqrt{h_3}];$$

and when the orifice may be covered with water on the under side, the heads h_1, h_2, &c., must be replaced by the differences of the heads on the upper and under side at the same periods of observation; that is to say, h_1 becomes $H_1 - h_1$, and h_2 becomes $H_2 - h_2$, &c., calling H the head on the upper, and h that on the under side of the orifice.

In all rivers there will be found to exist a greater or less extent of comparatively still water in immediate proximity to the bank, which also appears to form a series of eddies, arising probably from the impulsion of the current. The principal direction of these eddies appears to be opposite to that of the current; and when any obstacle is offered to the onward flow of the latter, the water becomes heaped up, as it were; and in this case also a kind of return takes place, from a change of direction in the flow of the liquid. A dyke or embankment in a river will produce this effect; or, in fact, any construction which diminishes the passage, such as groins, bridges, &c. There is no word in the English language which expresses this effect, and it may therefore be as well to adopt the French phrase "remous" to express the increase of height and the change of direction produced in a current by the intervention of any obstacle to its flow.



In the case of a dam across a stream, the bed of which is represented to an exaggerated scale by the line A B, and the dam by E F, the water will rise on the upper side to fall subsequently over the edge of the dam. The fluid mass represented by A′ *a a* C D will constitute the remous.

The greatest depth of the remous, excepting in so much as it is modified by the conditions mentioned in the next sentence, will exist immediately over the edge of the dam E F, and will be derived from the height of the latter, diminished by the original depth of the water, and increased by the height of water standing on the edge. This last quantity has been ascertained by M. Castel to be obtained by the formula $x = 0{\cdot}64 \sqrt[3]{\left(\frac{Q}{L}\right)^2}$, in which Q = the volume of the current, and L the width of the dam. Should the water, however, instead of falling over the edge, be withdrawn by a series of sluices at the lower part of the dam, the greatest depth will be equal to the distance between the center of the openings and the bed, added to the distance between the center and the top level, which will be found by making $x = 0{\cdot}1805 \frac{Q^2}{A^2}$, a being the sectional area of the openings.

But the greatest height of the water above the horizontal line does not take place immediately upon the dam; it occurs at a small distance above it. The same thing happens in this instance as in all others where water flows over a weir, viz., that shortly before it arrives at the edge it slopes towards the latter, and in large remous this sloping will begin at a considerable distance above. The height of the remous at any distance from the edge of the dam will result from the nature of the curve assumed by the surface of the water on the upper side. This is unquestionably a hyperbola, whose summit is at A′, whose axis is AC, and which is nearly tangent to a line passing through A at such a distance that $EG = \frac{2\,EH}{l}$, in which expression l = the length of the dam.

During the inquiries conducted by the Italian engineers for the purpose of discovering a simple self-acting gauge for the irrigation of that country, a very interesting fact was noticed which indicated that the ordinary laws of hydrostatics were, to some extent, modified when the water was set in motion.

It was ascertained that in a vase, constantly supplied, but divided into two portions by a diaphragm susceptible of being moved vertically, and with a discharging orifice on one side, a constant difference of level existed so long as the water flowed; and that this difference of level was greater in proportion as the opening of the diaphragm was less, compared to that of the orifice. And if, by any change in the direction of the supply, or of the flow, the level were made to alter on either side, the corresponding variations upon the two sides of the diaphragm continued to be always proportional with the respective differences of level first established. This law is not affected by the introduction of two or more diaphragms; for a similar variation of level takes place between each of them, and is maintained so long as the water continues to flow. Of course, if the discharge cease, the hydrostatic pressure will cause the water to assume the same level in all the communicating compartments.

If we suppose a fluid to be contained in a reversed syphon, each of whose branches is of the same diameter, it will be found to stand at the same level in both of them; and if by any means the column be now raised in one, and then left free, it will descend below the original level in consequence of the velocity acquired; it will remount above that line, and continue to oscillate about it for a certain time. These oscillations are found to be isochronous, and if the branches of the syphon be vertical, their duration will be equal to that of a pendulum whose length is equal to half the total height of the liquid column.

When any point on the surface of a pool of still water is disturbed, a series of small waves is formed, which extend with great rapidity. These waves are found to be of two sorts: the first are formed at the same moment in great numbers, and are propagated in every direction with a uniformly-increasing velocity, like that of the fall of heavy bodies, and the distance of any two summits increases in the direct ratio of the square of the time; whilst the heights decrease in the inverse ratio of the same square when the liquid is contained in a channel of a constant width, or according to the fourth power of the time when the liquid is entirely free. The second series also rise in infinite numbers and at the same time; but they are propagated uniformly with a velocity proportional to the square root of the diameter of the shock: the heights of the summits decrease in the inverse ratio of the square root of the time, or of the first power thereof, according to whether the liquid be contained in a channel, or entirely free. The second description of waves are more appreciable than the first, especially near the point of origin; and any wave which is formed on the surface of a liquid mass is propagated to a considerable depth in the interior.

When the waves come in contact with a fixed body, they are interrupted in a portion of their course, and that portion of the wave which strikes the resisting body is reflected back upon itself, and propagated in an opposite direction; they are, however, re-formed beyond the obstacle, if it be isolated, and extend beyond it as though they had not been interrupted. When several centers of disturbance are formed in a piece of still water, the series of waves may be observed to cross one another without any decided interference. These observations, however, are only applicable to small bodies of water; in the subsequent portion of this treatise attention will be more particularly called to the laws affecting the interference of waves at sea.

Bodies moving in fluids meet with two species of resistance, the one arising from the movement communicated to the portions of the liquid successively displaced, and the second arising from the power necessary to separate the parts of the liquid between which the bodies move. Up to a certain velocity the resistance of fluids from the first cause is found to be equal to their density: to the square of the sectional area of the body moving in them, modified to a considerable extent by their forms; and to the square of the velocity. The resistance arising from the cohesion of the fluid was found by Coulomb to be proportional to the velocity; to be independent of the nature of the surface of the body; and the pressure to which the fluid is exposed to be equally without influence on the value of the resistance. Thus any body moving in a liquid meets with a resistance composed of two terms; the one due to the inertia of the liquid increasing as the square of the velocity, the other due to the cohesion increasing simply with the velocity.

The researches of Mr. Scott Russell upon the movement of canal boats at high velocities show, however, that beyond a velocity of about 13 feet per second, some new, and hitherto but imperfectly understood laws come into operation. In the words of the Report of the British Association for the Advancement of Science, our present knowledge of the subject may be thus expressed:—"The resistance of a fluid to the motion of a floating body will rapidly increase as the velocity of the body rises towards the velocity of the wave of displacement caused by the said motion, and it will be greatest when the two velocities approach equality.

"When the velocity of the body is rendered greater than that due to the wave, the motion of the body is greatly facilitated. It remains poised on the summit of the wave in a position which may be one of stable equilibrium; and this effect is such, that at a velocity of 9 miles per hour the resistance is less than at a velocity of 6 miles per hour, behind the wave. The velocity of the wave is independent of the width of the fluid, and varies with the square root of its depth.

"It is established, that in every navigable stream there is a velocity at which it will be more easy to ascend against the current, than to descend with the current. Thus, if the current flow at the rate of 1 mile per hour in a stream 4 feet deep, it will be easier to ascend with a velocity of 8 miles per hour on the wave than to descend with the same velocity behind the wave. The velocity of the wave of displacement itself is about 8 miles per hour."

Projectiles, when they strike the surface of a liquid, meet with a resistance which diminishes their velocity and changes their direction. The intensity and direction of this resistance depend upon the form of the body, and its velocity. At all times, however, it tends to raise the direction of movement and to carry it towards the surface of the liquid; should the original direction of the projectile be but slightly inclined to the horizontal line, the shock will even cause the projectile to rebound as if the surface had been solid. It is for this reason that stones thrown from a small angle, or bullets fired from batteries near the water line, rebound a great number of times before their velocity is sufficiently retarded to allow of their sinking permanently below the surface.

When a fluid is in motion a certain portion of the force by which it is animated may be employed to drive a machine. Of course the motion thus utilized must be owing to the gravity of the water itself, for if it were necessary to give rise to it by the application of some other force, it would evidently be preferable to apply that force directly to the machine. In the useful arts, then, water is only applied when it flows in an inclined channel, or when it falls suddenly from a height. But it must be observed that, whatever be the nature of the machinery employed to transmit the power of the water, a certain portion must always be lost: 1st, because the whole velocity cannot be destroyed, or the water after producing its effect could not flow away; and 2nd, because the intermediate machine transmitting the power of the water has a motion and a velocity proportionate to the latter, which consequently can only act by the excess of its velocity over that of the machine.

Water may act as a motive power in several different ways; either by percussion, by pressure, or by reaction. It acts by percussion when it strikes the portions of any machine placed in its course, and, after communicating its movement to the machine, flows away immediately after the shock. Float-wheels placed in a current are illustrations of this action. Water acts by simple pressure when, having no initial velocity, or one which is very small, and only equal to that of the body on which it acts, it moves this merely by its weight; as in the case of bucket wheels when the velocity of the periphery of the wheel is equal to that of the stream. Water acts both by percussion and pressure when it falls upon a bucket wheel with a velocity greater than that of the wheel itself. And lastly, water produces its effect by reaction in turbines, or the class of mills called reaction mills for this very reason. In the case of the hydraulic press, the law by which a liquid inclosed in a vessel on all sides is able to transmit to every portion of its bounding surface a pressure exercised upon any one point thereof, is called into action. But as the details of these various machines form part of the science of practical mechanical engineering, rather than of civil engineering itself, the reader is referred to the other Numbers of this Series, in which that branch is more particularly considered.

PNEUMATICS.

Correctly speaking, the term Pneumatics ought to be confined to the science of the phenomena connected with the atmosphere; but by extension it has been made to include all the gaseous fluids. Our observations will, however, be confined as much as possible to the narrower acceptation of the word; and the gaseous fluids, other than the atmosphere, will only be treated of as connected with the latter.

As was already observed in the Section on Hydrostatics, gaseous fluids differ from aqueous fluids in this—that the former are highly elastic, whilst the latter are only very partially so. Of the gases themselves, again, there are some which are permanently elastic, and others which by means of compression can be converted into liquids. *Air* is an illustration of the former, steam of the latter class; but Faraday's beautiful researches lead to the belief that this distinction only exists in consequence of the imperfection of our means of operating upon them, and that all gases are susceptible of being condensed, under favourable conditions. In ordinary language it is, however, convenient to retain the distinction between the condensible and the incondensible gases; giving the former the specific name of *permanent gases*, and the latter that of *vapours*.

The properties common to all gases may be stated as follows:—1stly, that their elements have weight; 2ndly, that they tend constantly to dilate, in consequence of the repulsive force of their latent caloric exceeding the molecular attraction, and that they only retain the same volume from the resistance of some containing body; 3rdly, that they are compressible by reason of the space around their molecules; 4thly, that they are elastic, inasmuch as, when the molecules are brought into closer connection with one another, the repulsive force of heat increases more rapidly than the attraction; 5thly, that their molecules are perfectly free to move on one another; and 6thly, that by reason of their elasticity a force exercised on one point must be transmitted throughout, and in every direction. All these properties have been demonstrated to be possessed by atmospheric air.

Since the atmosphere possesses weight, compressibility, elasticity, and the power of communicating pressure in every direction, it follows that any portion of it must be pressed by the weight of that immediately above it, and must also transmit the effect of this weight to the portions below it; consequently the density of the atmosphere and its elasticity must decrease as the distance from the earth increases. A body thus placed in the air must therefore be exposed to a pressure upon every part of its surface which diminishes with its elevation.

The atmosphere revolves with the earth, and at the same velocity with it; for otherwise the air at rest would create a resistance to motion equal to the shock which would ensue if the earth stood still. A current of air, in fact, would be felt, whose velocity would be equal to that of the earth's rotation on its axis, or about 1518 feet per second; whilst the most violent hurricanes, such as are able to tear up trees and overthrow buildings, do not travel at a rate exceeding 147 feet per second. As the atmosphere moves with the earth, all the molecules composing it are affected by three forces—gravity, elasticity, and the centrifugal force. Under these circumstances, as the weight and the elastic force of the molecules of the atmosphere diminish in proportion to its distance from the axis of rotation, whilst, on the contrary, the centrifugal force increases, there must necessarily exist upon any vertical passing through the center of the globe a point where these three forces are in equilibrium, and the atmosphere must be limited. It has been ascertained that the distance at which the atmosphere becomes rarefied to such a degree as to be 760 times lighter than it is at the ordinary level of the earth—a rarefaction equal to that obtained by the best pneumatic machines—is about 58,000 yards above that level. This is not more than $\frac{10}{1225}$ of the radius of the earth; so that it may be considered that the height of the atmosphere is about equal to $\frac{1}{100}$ of the radius.

If a tube be made air-tight and filled with any liquid so as effectually to exclude the air, and then immersed in a vessel filled by some other liquid whose surface is exposed to the pressure of the atmosphere, it will be found that a column will be sustained in the tube, the height of which will depend upon the specific gravity of the liquids, and be in the inverse ratio of their density. The force which sustains these columns is the pressure of the atmosphere acting directly upon the exposed surface of the vessel, and pressing it in a downward direction, whilst the liquid in the tube is exposed to no such action; and the effect will be the same, whatever be the section and dimensions of the tube, provided they be not so small as to allow capillary attraction to modify it. Moreover, this pressure of the atmosphere may be demonstrated to act on every side, for if the tubes be made to assume any direction, the liquid in them will rise to the same height above the level of that contained in the vase as it would in a straight tube.

As the heights of the liquid columns suspended in the tubes are precisely in the inverse ratio of their densities, their weights must be exactly equal. Under these circumstances, as it is known that the atmospheric pressure will sustain, on the average, a column of mercury 30 inches in height, it will also sustain a column of water about 34 feet high, since the specific gravity of mercury is 13·56. But as the pressure of the atmosphere varies within a range of 3 inches of the mercurial column, the height of the column of water will also vary proportionally, or within a range of 3 feet 5 inches nearly. The atmosphere itself must exercise a pressure of 15 lbs. on every square inch, or the weight of a vertical prism of air 1 foot square on the base is about 2100 lbs.

It is to the pressure of the atmosphere that the ascent of water in a tube, from which air is exhausted, is owing. The removal of a certain portion of the air causes that which remains in the pipe to dilate, its elasticity then diminishes, and the liquid rises in the tube until the weight of the column thus raised and the elasticity of the dilated air balance the external pressure of the atmosphere. It follows that, for the same dilation of the air, the liquid will rise to a height which will be in the inverse ratio of its density.

It must be evident, from what has been said above, that the height of a liquid column of any description might be taken as the measure of the weight of the atmosphere. But it has been found more convenient to adopt mercury as the standard of comparison, because it admits of the column being made shorter than for any other liquid; and also because it is not so likely to give off vapours (whose elasticity would to a greater or less degree falsify the indications), as the majority of liquids are liable to do. Even mercury itself gives off a vapour, but, within the ordinary range of the temperature, its elasticity is so small that it may be neglected without inconvenience. In the arts, then, we find that, almost invariably, tubes in which columns of mercury are free to move, according to the weight of the atmosphere, are used to ascertain the pressure of the latter, and are known by the name of barometers.

In engineering the barometer is principally used for observations upon the weather, or for ascertaining comparative altitudes. As these subjects are, however, more particularly treated in the Number of this Series especially devoted to Pneumatics, the student who might desire further information on the use of the barometer is referred to it, or to the works cited at the end.

It is a necessary consequence of what has previously been stated, that when a gas is compressed, it diminishes in bulk, and as its elasticity increases with its density, it must sooner or later arrive at such a state of condensation, that the elastic force shall be equal to the pressure exercised; but the laws affecting the condensation and the elastic force are yet but very imperfectly known. Practically, and especially in the case of atmospheric air, it may be considered that the pressure exercised by a gas against the side of the vessel which contains it, is increased in precisely the same proportion as the space which it occupies is diminished ; or, in other words, the elastic force of the air, or of any gas, is proportional to its density. It must be observed, however, that a variation in the temperature will affect the conditions of elasticity; because an increase of temperature will give rise to an increase of elasticity without, or even in spite of, any variation in the density.

One consequence of the elasticity of gases is, that they exercise a pressure upon their containing vessels independent of any mechanical, or external, pressure, and in this respect they differ from ordinary fluids. The energy of this pressure depends upon the difference between the elasticities of the contained and the surrounding gas, independently of any pressure which may be applied to the former.

Pneumatics are more immediately connected with the practice of civil engineering in the principles regulating the construction of pumps and syphons. Pumps are of several descriptions, and every maker has his own peculiar fancies with respect to their details; but the only real distinctions, at least of such pumps as usually are made with a view to employ the atmospheric pressure as far as possible, are the suction and the forcing pump.

The suction pump consists of a vertical pipe immersed in water at the lower end; of a piston moving in a portion of the cylinder; and of two clacks, or valves, one of which is seated upon the pipe, and the other upon the piston itself. If in such a pump, of the construction usually adopted, we suppose the piston to be at the bottom of the cylinder, and nearly in contact with the lower valve, upon raising the former, the valve upon the piston itself will be closed by the weight of the atmosphere, and a partial vacuum will be formed under it. The air in the pipe and the barrel of the pump will become rarefied, and unable, therefore, to press upon the surface of the fluid immediately beneath it with the same force that the external air presses upon the water in the vase; the latter force being then no longer balanced, a column will be raised in the pipe whose height will depend upon the atmospheric pressure, and the perfection of the vacuum. If we further suppose the water to rise to a certain height in the cylinder, and that the piston then descend to the position first assumed, the air between it and the water will escape through the valve, and the water will still further rise in the pump, until at last the piston plunges into it, and the water rising through the valve is retained above it by closing the latter, which is made only to open upwards. On the return up-stroke the water above the valve is raised by the piston to the outflow, a second vacuum is created beneath it, and a further portion of the water in the containing vessel is made to enter the pipe by the atmospheric pressure.

The height of the lifting pipe we have seen to depend upon the perfection of the vacuum created, nearly as much as upon the atmospheric pressure. Instead, then, of being able to raise water about 34 feet, as we should be entitled to expect theoretically, it is very rarely that suction pumps can be made to work at greater heights than from 16 to 28 feet; and in all such machines the chances of diminished effect increase with the dimension of the pump itself. In practice the height is usually made about 24 feet; and the diameters of the suction and ascending pipes are usually made from $\frac{1}{3}$ to $\frac{2}{3}$ of that of the pump barrel. It is necessary, in order to secure the greatest results from such pumps, that, when the piston descends, it should touch the lower clack, so as not to leave any space between the latter and the under side of the piston. The power to be applied to the handle must be in excess of the sum of the weights of the column of water above the piston, and of the column in the ascending pipe, and also be able to overcome the friction of the various movements of the machinery.

The forcing pump may be either a *lifting* pump, when the column of water is raised directly upon the piston, or a *forcing* pump, when the water is driven by the piston into an ascending pipe. It is usual to combine the suction pump with both of these varieties of the forcing pump, in order to use the atmospheric pressure as far as possible.

Evidently any kind of pump, in which the whole weight of a liquid column has to be set in motion at each stroke of the piston, must be so disadvantageous that it will not be matter of surprise that the ordinary lifting pump should rarely be used; nor will it be worth while to dwell upon it here, further than to say that it is, in fact, nothing more than the suction pump already described, the upper tube of which has been prolonged. The forcing pump consists of a barrel and a suction tube, separated by a clack, opening upwards into the barrel. The piston, instead of carrying a second clack, is solid, and the clack is placed at the entrance of the ascending pipe, which usually branches from the barrel in a horizontal direction for a short distance, and then ascends vertically. The motion of the second clack is from the barrel outwards.

The action of such a pump will be analagous to that of the suction pump, until the water rises into the barrel from the atmospheric pressure; because the piston will rarefy the air beneath it, and the unbalanced pressure upon the containing reservoir will cause a column of water to flow into the tube. When the water has entered the barrel, at the next down stroke of the piston, the latter will cause it to force open the foot valve and to rush into the ascending column. The pressure of the water in this column must act upon its base with a weight proportionate to its height, and if then a motive force be employed in excess of this pressure, the water can continue to be lifted to a height proportional to the supposed motive power.

In those suction and forcing pumps in which the water does not rest upon the piston, the effort necessary to raise the latter is only that which would be required to raise a weight equal to that of the column of water raised by the suction. But in descending, the piston compresses the water, and causes it to pass through the foot valve and to rise in the ascending column; and consequently it requires a power able to move the weight of the latter. There must evidently be a great advantage in equalizing these actions, which it is always easy to do, when the total height to which it is required to raise the water does not exceed 56 feet, by merely placing the pump barrel in the middle. Beyond this point, it becomes necessary to adopt mechanical arrangements to communicate greater power to the descending than to the ascending stroke of the piston. It is in such cases that the application of steam power produces some of its most useful results.

The piston of forcing pumps was formerly always made of wood, or of metal, packed with leather so as to work closely against the sides of the barrel; but latterly the *plunger* pumps have been more generally used. The *plunger* is a metallic cylinder, either solid or hollow, and of a length a little greater than that of the stroke; the diameter being from ½ inch to 1 inch less than that of the barrel. The packing is fixed, and is in fact formed by the stuffing box. The plunger in descending takes the place of the water which it drives before it; and in ascending it creates a vacuum in the suction pipe.

In any pump, theoretically, the useful results would be represented by the formula $Pm = Wh$, in which we have

Pm = the motive power employed;

W = the weight of the water raised; and

h = the height to which it is raised above the well.

Practically, however, the effect is diminished by the friction of the packing, of the piston rod, and of the column of water against the sides of the various pipes; the weight and the friction of the clacks diminish the effect, as also must the variations of the direction and velocity of the ascending column, to which the velocity of the stream at the point of discharge must be added. In the most perfect pumps it is possible that $Wh = 0{\cdot}75$ to $0{\cdot}85\ Pm$; but ordinarily the coefficient of useful effect rarely attains 0·75.

Several machines depending upon pneumatical principles are used occasionally in hydraulic engineering, such as the diving bell, camels, floating docks, &c.; but their details belong so much more especially to other branches of practical mechanics, that it may suffice here merely to allude to them. But the application of the motive power of winds to land drainage is often of so great economical use, that it may be advisable to dwell upon it somewhat more in detail.

Smeaton, in a paper communicated to the Royal Society, 1757, drew up the following table of the velocity and perpendicular force of the wind in different circumstances:—

Miles per Hour.	Feet per Second.	Perpendicular Force on One Square Foot, in Avoirdupois Pounds and Parts.	
1	1·47	0·005	Hardly perceptible.
2	2·93	0·020	Just perceptible.
3	4·4	0·044	
4	5·87	0·079	Gently pleasant.
5	7·33	0·123	
10	14·67	0·492	Pleasant, brisk.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36·67	3·075	
30	44·01	4·429	High wind.
35	51·34	6·027	
40	58·68	7·873	Very high wind.
45	66·01	9·963	
50	73·35	12·300	Storm, or tempest.
60	88·02	17·715	Great storm.
80	117·36	31·490	Hurricane.
100	146·7	49·200	Hurricane, tearing up trees and overthrowing buildings.

A wind below the velocity of 10 miles per hour is not able to insure the working of a corn mill; when the velocity exceeds 20 miles per hour, it becomes necessary to furl the sails. This last velocity is considered to be the most suitable for the purposes of navigation.

According to Smeaton, a windmill yields the greatest effect when its sails are made with inclined surfaces, the generating lines of which, situated at points obtained by dividing the length of the sail into six parts, form with the axis of the wheel, or the direction of the wind, the angles indicated in the following table. (The generating line, No. 1, is that which is the nearest to the axis, and it is at this point that the sails begin.)

No. of generating Line.	Angle with Axis.	Angle with Plane of Movement of the Sails.	Observations.
1	72·00°	18·00°	The angles of the third column are the complements of those in the second.
2	71·00	19·00	
3 middle	72·00	18·00	
4	74·00	16·00	
5	77·50	12·50	
6	83·00	7·00	

It is usual to make the width of the sail vary between $\frac{1}{5}$ and $\frac{1}{6}$ of the length, and never to exceed $\frac{1}{4}$ of that dimension.

From the same authority it appears, that when the sails of a mill are well filled the velocity of their extremities without a load is equal to four times that of the wind; and that it is necessary that the velocity of the extremities should be 2·5 or 2·7 of the velocity of the wind, in order to obtain the maximum effect. The useful effects produced are in the ratio of the cubes of the velocity of the wind, and may be represented by the formula $P = \frac{v^2 a^2 \sin^2 \theta}{440}$, in which $P =$ the impulse in pounds avoirdupois; $v =$ the velocity in feet per second; $a^2 =$ the area of the sail in feet; $\theta =$ the angle to the direction of the stream.

In Holland windmills are extensively used for the purposes of drainage, and it is there the practice to employ one mill, with sweeps of from 80 to 90 feet diameter, for every 1250 acres, and for a lift not exceeding 5 feet. These mills work, on the average, 60 days in the year, and raise a total quantity of 695,220,000 cubic feet of water 1 foot in height. Further details connected with this portion of engineering operations will be found in the next chapter.

The syphon depends upon the atmospheric pressure for its power of action, and is employed so frequently as to warrant an examination of its principles in this place. It consists of a bent tube, open at both ends, one branch of which is plunged into a reservoir. If such a tube be filled with a liquid of any kind, the elastic force of the atmosphere may practically be considered to be in equilibrium on both sides, because the difference of level between the two branches is never sufficiently great for any appreciable inequality of pressure from this cause to affect the motion of the fluid, which, under such circumstances, must be entirely owing to gravitation. Now, the liquid columns in the respective branches have a tendency to fall away from either of them; but this cannot occur, for directly a void is left in the upper portion a considerable difference takes place in the atmospheric pressure; so that as long as motion exists through the tube, it must take place in one direction. Consequently, if one side be longer than the other the liquid will flow through it, and the pressure of the atmosphere upon the surface of the liquid in the vase will keep the tube full until the level of the fluid in the vase descends to that of the opening of the shorter branch. It is evident that the syphon can only act within limits varying with the densities of the fluids to which it may be applied; thus, for water, it would be impossible to make it act beyond a height of 34 feet, and this theoretical limit is rarely attained in practice.

There are many other phenomena connected with Pneumatics, of great general interest, and even of frequent useful application, such as those connected with the movement of gases in pipes, aerostation, sound, evaporation, distillation, &c., to some of which it will be necessary to refer hereafter, in the consideration of the practical details of Hydraulic Engineering. In the mean time, should the reader require further information upon the subjects contained in these preliminary remarks, he is referred to the Treatises of this Series on Hydrostatics, &c., Pneumatics, and to the list of authors to be found in the appendix.

DRAINAGE AND IRRIGATION.

The functions of vegetable life cannot be carried on without the presence of a certain quantity of water, inasmuch as the fluids which circulate in their tissues are almost entirely composed of the water taken up by the roots from the ground. With the exception, however, of some aquatic plants, the majority suffer from an excess of humidity; and when water is found in an agricultural district in large quantities, it is as injurious as its absence is in other cases. Thence arises the necessity for *draining* lands surcharged with water, on the one hand; and for *irrigation*, on the other. It is equally important that air should be allowed access to the roots of plants; but the operations of ploughing, harrowing, hoeing, &c., by which this object is effected, belong to the science of agriculture rather than to engineering.

The causes of the excess of moisture in any particular district depend upon the rain-fall, the natural configuration of the land, and the nature of the surface and the subsoils; and, conversely, the same causes influence the dryness of other districts.

The distribution of rain is very unequal, not only when large divisions of the globe are considered, but also over very confined areas. This is a natural consequence of the laws affecting the production of rain; for it is caused, firstly by the heat giving rise to evaporation, and then the winds carry the vapour to a distance, until it is precipitated, either by contact with the cold earth, or by meeting with another mass of air so much colder as to absorb the heat which holds the moisture in solution. In the tropical regions, the rain-fall is greatly in excess of that of the temperate zones; but from the greater uniformity of temperature, it also happens that the fall is confined within a much more limited space of time; the total quantity is greater, but the number of rainy days is less, and the law appears to prevail that the number of rainy days increases with the latitude. But local circumstances modify these general laws to a great extent; so much so, that in nearly the same parallels of latitude one district may be subject to frequent floods, whilst another may be constantly or periodically exposed to droughts.

The quantity of rain, for instance, is always less in plains than in elevated table-lands, especially when the latter are connected with mountain chains. On the sea shore also, it is greater than in inland districts, because more vapour rises from the sea than from the land. The existence of particular currents in the ocean will at times give rise to an excess of rain on the shores round which it flows, an instance of which may be cited in the gulf stream which causes the great rain-fall in the southern and western counties of England and in Ireland. The prevalence of certain winds will augment or diminish the quantity of rain, according to whether they blow over surfaces able to affect in any way the amount of evaporation. Thus, in Europe, if the wind blew always from the north-east, it would never rain; whilst if it always blew from the south-west, the rain would never cease on the sea coast. It is to these various causes we must attribute the local differences between the number of rainy days, which, in the instance of Ireland, are about 208 out of the total 365; in that of the greater part of England, France, and the north of Germany, they vary from about 152 to 155 rainy days in the year; and in that of Siberia, it is stated that the number falls to 60. Nor are the quantities falling less variable than the number of the days, for we find that the total quantity registered near London is, on the average, about 24¾ inches per annum; whilst near Plymouth it is about 38 inches; at Manchester, 37¼ inches; at Seathwaite, 140·6 inches; at Glasgow, 33½ inches; and near Edinburgh, at Glencorse, in the Pentland Hills, 36¼ inches.

The natural configuration of the country affects the amount of moisture retained, by the greater or less facilities it may offer for its removal. Evidently, a district presenting sharp declivities on every side, with few depressions to hold water in pools, must not only throw off the latter with great rapidity, but also furnish few means of maintaining evaporation, when the fall of rain shall have ceased. The outline and direction of the watercourses also materially influence the length of time during which the water may be retained. And, indeed, the majority of cases in which marshes occur may be attributed to the physical causes connected with the surface of the earth; either, in fact, to the existence of a zone of surrounding country at a higher level, or to the existence of a watercourse in a similar relative position.

The natures of the surface and of the subsoils produce effects upon the humidity of a district which are more readily under control than the causes previously alluded to. They act either by retaining the surface waters, or by giving passage to the springs fed by lands at a greater distance; and it is of the utmost importance to be able to distinguish between these two sources of humidity, as the surface drainage adapted to the first, under some circumstances, is utterly ineffectual to remedy the second.

For drainage operations, the strictly correct geological descriptions of the various strata may be neglected, and they may be divided simply into two classes, the *porous* and the *impervious*. The former comprises all those consisting of loose materials which absorb water easily and allow of its passing freely, such as gravel, sand, loamy clays, and the comminuted upper strata of most of the limestone formations. The latter consists of stiff blue clays, or of the plastic clays found in such abundance; of some kinds of gravel cemented by argillaceous, calcareous, or ferruginous materials; and of such limestone, sandstone, or granitic rocks as present a close grain without any fissures. No regular order of superposition of these classes of strata exists in nature, and from their complication arise the greatest difficulties in drainage.

In such cases as those in which a pervious stratum lies upon an impervious one, the water falling from the clouds permeates the former until it meets the latter. If, then, no escape be furnished by some natural overflow, the water must accumulate in the lowest depressions, until the hydrostatic pressure of that in the higher portions forces it to the surface in any lower ones whose conditions of level may be such as to allow of its rising. It may frequently happen, that a natural overflow exists at a small distance from the surface, but not at such a depth as to prevent the existence of great moisture in the main body of the stratum, although no external indication beyond the character of the herbage may indicate the moisture. The great objects, therefore, in all drainage are, not only to remove the surface waters, but more particularly to cut off the subterraneous waters, which either rise to the surface or are confined beneath it.

The removal of surface waters is a comparatively simple operation, for it may be effected by dressing the land into ridges, and giving these an outfall into a drain or ditch all round the field. The ditch itself would pour its waters into any natural course, and the latter may at any time be enlarged or improved, by observing the principles regulating the flow of water in open channels, laid down in page 56, and subsequently, of this Part. The conditions to be observed being, that the channel should be able to carry off, at a suitable velocity, the maximum quantity of water likely to be thrown into it within a definite period; and that the velocity should not be such as to endanger the bottom or the sides. If the outfall drain be artificially made, it is, generally speaking, desirable that it should be impermeable.

Operations connected with the improvement of an outfall affect very large areas, and would seem almost to call for some action of the Legislature. In many individual cases, so to speak, it is beyond the power of one proprietor to undertake them; and the only course left open to him is, to isolate his own land by diverting any water flowing from other districts, and to remove that which falls upon his own, by means the most adapted to effect that object economically.

The execution of an intercepting drain will very frequently suffice to remove all the subterranean waters, should such be found, by stopping the flow of the latter in what would otherwise be their natural direction, and thus leave merely the rain-water falling over the particular district to be dealt with. In such countries as Holland, and the fens of Lincolnshire, Bedfordshire, &c., the intercepting drain itself becomes the outfall, and a means of communication; for the main drains are used as canals, and the waters from the low lands are pumped into them either by windmills or by steam power, as may be most expedient.

In hilly countries it rarely happens that any difficulty occurs from the direction or inclination of the watercourses, and in them the question of outfall is not so complicated as in the lower and more level districts near the embouchures of rivers. The longitudinal section of the center line of nearly all rivers is, in fact, a concave parabolic curve, the apex of which is in the elevated grounds near its source. The velocity, under such circumstances, is very great in hilly countries, and the streams are able to keep their course in a tolerably straight line, if even they do not continually tend to rectify any bends which may naturally exist. But in proportion as the rivers approach the sea, or other large rivers, they usually flow through flat alluvial deposits, or through level plains of earlier formations. The velocity of the water diminishes, and the gradual deposition of matters brought down from the hills raises the bed of the river, whilst the direction becomes tortuous from the incapacity of the stream to overcome the obstacles to its progress. In no country in the world can more striking illustrations of these laws be found than in England; nor, perhaps, is there any country where well-directed works for the purpose of obviating their inconveniences would be attended with more brilliant results.

Before commencing any rectification of the bed of a river or stream, it is necessary to inquire carefully into all the numerous commercial interests which are likely to be affected by the alteration. A plan of the existing watercourse and its various affluents, with longitudinal and transverse sections of the beds and banks to a considerable distance on either side, is required; observations upon the flood and summer levels, and upon the seasons and duration of the changes in the volume of the stream, must be made; and, lastly, a careful notice must be taken of the nature of the materials carried down, the mode in which shoals are formed or the banks destroyed, and the nature of the river-bed in its normal state.

If the stream follow a very tortuous course, a new channel in a direct line evidently will shorten the distance between its extreme points, and increase the inclination of the water line. The velocity of the stream will be proportionally augmented, and if the same quantity to be discharged flow before and after the execution of the new channel, its sectional area may be made smaller; or if, on the contrary, it be made of the same area as the original channel, it will be able to discharge a greater volume. Any sudden bends may thus be avoided; but it is to be observed, that there seems to exist some law, the cause of which has hitherto escaped our analysis, owing to which rivers are not able to flow in straight lines for any great distance, in other than beds of masonry, without requiring great and frequent repairs. At any rate, every stream when left to itself, so to speak, assumes a tortuous outline; and, from the experience obtained in France and Italy, it appears, that after a deviation there is always a tendency to resume the original directions, especially during the seasons of floods. It is, therefore, preferable that the center line of a new channel be formed with a series of curvatures of very large radius, rather than in a perfectly straight line. Upon the Rhine it was found that the river exercised no corrosive action upon its banks when the radius of curvature was about 2750 yards long, the bed of the river consisting of sand and gravel, and being frequently exposed to sudden and violent floods.

The efficient action of new channels can only be attained by observing these conditions:—Firstly.—They must be deepened as much as possible; the sectional area to be given will of course be regulated by the volume to be discharged under all the varying conditions of the rain-fall. Secondly.—They must not present any sudden projections, or form any sharp curves with the main stream. Thirdly.—If the new channel cannot be dug out at once to the required depth, it must not be opened to receive the waters until the *down* stream end of the old channel be closed, so as effectually to force all the running water into the new channel. Fourthly.—All obstacles, such as trunks of trees, large blocks of stone, &c., must be removed, so as to leave the watercourse perfectly clear.

When an entirely new outfall is to be formed, the dimensions to be given to it must depend upon the proportion of the rain-fall it may be required to carry off. This will vary, not only according to the configuration of the country, but also according to the greater or less degree of permeability of the materials. In precipitous mountain districts the rain flows off with comparative rapidity, merely from the inclination of the ground. Should, however, our observations be directed to particular mountain districts, it will be found that the discharge from granitic rocks differs very materially from that from the lias, the oolites, or the clay formations. From the granites, the rain runs off nearly as fast as it falls, for the materials are non-absorbent, and the subordinate outlines do not present any depressions likely to retain the water. The lias is also, comparatively speaking, impermeable, as are also the clays; whilst the oolites and the gravels absorb the water during the period of its falling, to give it out again when perhaps the supply may have ceased. In fact, the character of the discharge from the granites, the lias, and the clays, may be regarded as being of a torrential description, whilst that from the limestones is far more equable. In the former districts, it appears that about $\frac{2}{3}$ of the rain flows off in the natural watercourses, whilst in the latter and in the gravel the maximum quantity so flowing would only be $\frac{1}{3}$. Again, the proportion of the rain-fall which may require to be carried off will differ, according to the greater or less continuance of the rainy season. Thus, in winter it happens that the ground frequently becomes saturated with water at an early period, and it is advisable in such a case that any flood should be carried off as rapidly as it rises. The maximum quantity of rain which may fall within a given time becomes then a condition regulating the dimension of the outfall, of nearly as much importance as the average fall of the whole year.

An outfall having been secured, either by adopting or improving the natural facilities of the country, or by forming a new watercourse, if the source of the water deteriorating the quality of any land be not such as to be removed by surface drainage, an investigation of the surrounding district must be made, to ascertain the superposition of the strata, their nature, thickness, and respective inclinations; or, should any local circumstances prevent this examination from being carried out on a sufficiently extended scale, small ditches or trial shafts should be sunk at the upper and lower sides of the district to be drained. The points of outburst of any springs must be noticed, and, if possible, their sources of supply be discovered. When these points are settled, the direction to be given to the drains must be considered; and, if possible, it would be advisable to make them follow the line of the longest fall of the ground. The depth, and the distance apart of the drains, must depend to a certain extent upon the description of crops to be raised, but more particularly upon the nature of the subsoil. For, in the first place, it is necessary to place the drains at such a depth as to obviate any danger of their materials being deranged by agricultural operations. In ordinary modes of cultivation, the minimum depth to which the ground is worked may be taken at 8 inches; in many others, the ground is moved to a depth of 18 inches; and for these reasons it is usual to place the drains at such a depth that there shall be a distance of about 20 inches between their highest points and the surface of the ground. In the second place, if an impermeable subsoil be met with within a distance of 5 or 6 feet from the surface, such as to intercept the passage of the water in either direction, the drains must be carried down to it; or otherwise the portions between each of them would only be imperfectly dried. The nature of the materials employed will also modify the depth of the drains; for if they be bulky, as in the case of broken stone, they must require a greater width than when tiles or tubes are used.

The width of the trenches will be regulated by the depth of the drains, because the workmen require a greater space to work the deep than they do the shallow ones. At the surface the width is required to be greater than at the bottom; and in practice it is found that, for a depth of about 3 feet, it is sufficient to give a width of about 1 foot at the surface and of 6 inches at the bottom; for a depth of about 4 feet, those dimensions become respectively 1 foot 4 inches and 8 inches; whilst, for a depth of 8 feet, they become respectively 2 feet 6 inches and 1 foot 2 inches. The direction of the drains should be made as straight as possible, in order to avoid any interference with the discharge of the water; and they must be commenced by opening the lower portions of the district first.

It is indispensable that a regular inclination be given, and that it should be sufficient to insure the flow of the water. A fall of about 1 in 200 will be found sufficient for ordinary cases, especially if the drain tiles be well laid.

There are several modes of filling in drains employed by

Fig. A.

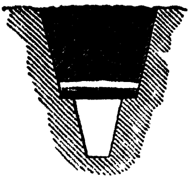


Fig. B.

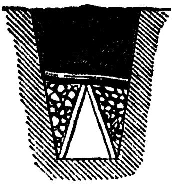
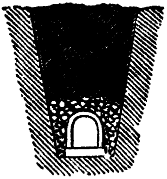


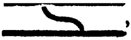
Fig. C.



agricultural engineers, the principal of which are represented in the subjoined sketches. Fig. A represents a simple and economical system followed in countries where tubes or stones are expensive. It consists in forming shoulders upon the sides of the trenches, and laying upon them a thick sod with the grass downwards, the remainder of the trench being filled in with the materials thrown out from it, taking care to reject the denser and more impermeable earths. This description of drain is economically formed, but it does not last for any length of time, at least with sufficient efficacy.

Fig. B represents an economical form of drain for countries in which large quantities of water are to be removed, and where stone is cheap. The channel is formed by placing thin slabs on edge, leaning against one another, and covering them with broken stones or gravel; the whole is then covered by sods and the lighter earths of the excavations, as before. If the waters draining through such channels do not contain any notable proportion of soluble salts, which they might gradually deposit around the broken stones, they will continue to flow for an indefinite period.

Fig. C represents the tile and shoe drains, which were much employed in England formerly, each tile being about 14 inches long, by 3 or 4 inches wide, and 4 or 5 inches high, and the shoes being of the same length, but a little wider than the tiles. Of late years, however, it has been the opinion of agriculturalists, that perfectly cylindrical tubes are the most advantageous, not only on account of the greater facility of their manufacture, but also of the greater economy in their fixing. These cylindrical tubes are made of the same length as the earlier descriptions of tiles, and of diameters varying from 1 to 3 or 4 inches.

When the soil is peaty, or a running sand, or when the nature of the materials through which the excavation is carried is such as to render it difficult to form and maintain the bottom of the trench in a perfectly straight line, the butting joints of the tubes will require to be protected by collars, which may be perforated with numerous small holes. Under ordinary circumstances, it will suffice either to use pipes with an end terminating thus , or merely with a straight end. In the last two cases, the trench should only be thrown out to the precise width necessary to receive the pipes; and in both it is absolutely necessary that the straightness and the uniformity of inclination of the bottom of the trench be rigorously observed.

Drains should not be made too long, because, if the fall be great there would be danger from the bursting of the pipes by the head of water; and the chances of choking are considerably increased, as well as the difficulty and expense of repairs. It is advisable to make the subdrains pour their water into a species of main of larger diameter, which subsequently should pour the collected stream into the general outfall. Mr. Parkes recommends that the submains should never much exceed 300 yards in length, and he usually makes the diameter of the lower half about ⅓ greater than that of the upper, in order to insure the perfect discharge of the water. Under ordinary circumstances, however, it is preferable that the smaller drains should discharge into an open ditch, because the water would flow away more easily, and at the same time the repairs are performed with greater facility.

The length of the main drains may be greater, on account of their greater dimensions, but the condition above stated, of giving them an enlarged diameter at their lower extremity, must be observed. They are formed in the same manner as the subdrains, but, of course, in the lowest parts of the land; and it is advisable to place them at a slight distance below the subdrains, in order that these may discharge more freely. Their inclination must be greater, because the volume of water they have to transmit is also greater than that of the subdrains; and it is important to carry them at some distance from the hedges, or large trees, lest the roots should force their way into the pipes and choke them, because these are known to have a remarkable avidity for water, and are likely to force their way into the joints of the pipes. Lastly, it is important that the junction of the subdrains with the mains should not take place at right angles, but in an oblique direction, so as to avoid any interference with the velocities of the respective currents which might be likely to cause the deposition of any sand or mud in suspension in either of them, For the same reason it is advisable, that two drains coming from different parts of the land should not be made to converge at the same point.

The distance apart of the drains will depend, in fact, upon their depth, and the degree of permeability of the soil; and this becomes one of the most important questions to be decided before commencing such works, for the greater the distance, evidently, the less will be the number, and the cost of the operation. Mr. Smith, of Deanstone, advocated the system of numerous drains, at comparatively shallow depths; whilst Mr. Parkes recommends that they be made deeper and at greater distances. The former made his drains from 6 to 8 yards apart, and about 3 feet deep; whilst the latter makes the distance from 13 to 20 yards, and the depth from 4 feet 6 inches to 8 feet. In fact, both parties may be in error in striving to enforce their respective systems too rigorously, and a course of proceeding which may be eminently successful in one case may be very inadvisable in another. Thus, if a stratum of permeable materials exist, whose depth may be 6 feet, it is possible that a drain placed 5 feet below the surface may withdraw the waters from a distance of about 10 or 15 yards on either side. In such a case, there would be a decided advantage in placing the drains at the greatest depths and distances, according to Mr. Parkes' plan. But if the soil itself be light, and at a depth of from 2 to 3 feet from the surface an impervious subsoil be found, it would be evidently absurd to carry the drains below the subsoil, because this would entirely destroy any lateral action of the drains beyond a distance of about 6 or 8 yards. In such cases, the system recommended by Mr. Smith is the more advisable; and, indeed, it happens in this particular branch of engineering, as in all others, that every individual case requires to be judged of and decided upon its own merits.

In Ireland the usual system latterly adopted appears to be so admirably suited to the class of materials most commonly met with, that an abstract of it is subjoined.

Minor drains are formed at distances apart varying from 21 to 40 feet; the depth is made 3 feet from the lowest point of the surface; the width, from 15 to 18 inches at the top, and 4 inches at the bottom. These minor drains are parallel to one another, and only run from 150 to 200 yards without falling into either a ditch or a submain. In these drains a depth of 12 inches of broken stones, 2½ inches in diameter, is placed, care being taken that they be quite clean; a sod 3 inches thick is placed over them, and the earth is filled in. Sometimes pipes 2½ inches in diameter are inserted.

The submains are cut 42 inches deep, by 20 inches wide at the top and 12 inches wide at the bottom; they are carried along the low side of the field, about 10 feet from the fences, and are not allowed to run more than 300 yards without discharging into a covered or main drain. An open channel, 6 inches square, is formed, and above this the trench is covered and filled in, as before, with a thickness of about 8 inches of broken stones, carefully cleaned.

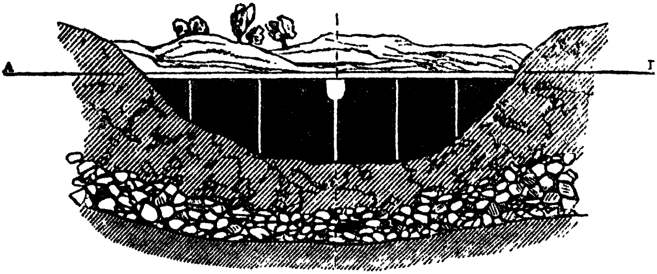
The open main drains are sunk to a depth of at least 5 feet;

they are made 2 feet wide at the bottom, and the sides are thrown out to an inclination of 1 to 1, if the materials be such as to stand at that inclination, excepting in rocky countries, where the sides may be left at about ½ to 1. A minimum inclination of at least 4 feet per mile is required for these main drains. The dimensions of the covered main drains must necessarily depend upon the quantity of water they are intended to carry off; but, generally speaking, it is found to be sufficient to make them 1 foot square in the clear, with walls 6 inches thick, covered by flag-stones 3 inches thick, and filled in as before.

It appears that there is an advantage in executing the drainage of an agricultural district in dry weather, and in leaving the trenches open for a short time, in order that the ground may become warmer, and to a certain extent aërated, by being exposed to the atmosphere.

The measures to be adopted for the drainage of marsh lands must necessarily depend upon the causes which have superinduced this state. These causes are the following, at least in the majority of cases:—1stly, the superabundant humidity of the land may be owing to the fact that the subterranean waters are retained by beds of impermeable materials, and, after saturating the lower strata, they are forced to make to themselves a vent upon the surface; 2ndly, it may be owing to the fact that the land is situated below the level of the surrounding country, and therefore receives the drainage from it; 3rdly, it may be owing to the existence of a river occupying a higher level than that of the marsh land itself.

The operations connected with the drainage of large marshes, fens, or bogs, require so serious an outlay that they can only be undertaken by large companies or by the State; but it frequently happens that small districts may be found in which a bed of clay occupies a position similar to that represented in the accompanying sketch, filling a depression upon the top of some permeable material, which last, in its turn, reposes upon a lower stratum of impermeable materials. In such cases the



clay will prevent the water which soaks through the upper and exposed portions of the permeable stratum from flowing away at the lower point. The water will then accumulate until it rises to the level of the surface of the clay, represented by the line A B, where it will overflow and form what are commonly called springs, which, unless provided with an outfall, will maintain the surface in a state of excessive humidity.

If, again, in the above sketch we suppose the basin-shaped depression shaded with interrupted lines to represent a bed of clay, resting upon gravel, and to be filled in with ordinary soil, from the known impermeability of the clay it will retain all the water soaking through the soil to it, and in fact render the soil a complete morass, especially if the soil in question be surrounded by any eminences shedding their waters upon it.

In the illustration first supposed, the waters may be removed, either by bringing them to the surface at a point where a new and more effective outfall can be found, or by letting them escape to a lower level. In the first case, surface drains are to be cut of a sufficient capacity to hold the waters likely to rise, and transverse outfall drains made to receive them. Borings should then be made in the surface drains, descending to the top of the upholding stratum, and the hydrostatic pressure of the supply, in such portions as are placed at a higher level, will cause the water to flow into the surface drains until its level throughout the whole district will be found to be that of the drains. The outfall must be made as usual.

In the second illustration a boring, or borings, as may be required, are to be made through the impermeable stratum to the pervious one upon which it reposes; or, in fact, a series of absorbing wells are to be formed, and the various surface drains made to converge to it. In the Treatise upon Well-boring and Sinking much information will be found connected with the principles of the action of such wells and their mode of construction. In these instances they will serve to carry the waters from the various surface drains into the lower strata, which almost invariably will be found to possess some natural outlet, at a greater or less distance, in the shape of a spring.

When the succession of strata outcropping upon a hill side is more complicated than in the cases above supposed, and is such as to produce an alternation of dry ground and marsh, the class of works to be executed may require to be somewhat different in detail, but in principle they will be found to be similar to those described. The object to be effected is, in all cases, to form a new outlet for the water; and whatever course be adopted, it must be based upon the ordinary principles of hydrodynamics applied to the particular configuration of the locality, which, again, can only be ascertained by a careful examination of the geology of the district. This examination may very frequently require to be extended over a considerable area, because the sources of supply of any springs may be found to exist at great distances, and until all the conditions affecting them are ascertained it is impossible to adopt any other than empirical methods of obviating their effects. Notwithstanding, then, the progress of science in our times, Mr. Elkington's rules may still be quoted as being the simplest and most effective for the execution of the drainage of marsh lands formed by the outburst of land springs. They are as follows:—

1st. To find out the main spring or cause of the mischief.

2nd. To take the level of the spring, and ascertain its subterraneous bearings.

3rd. To use the auger to tap the spring, when the depth of the drain is not sufficient for that purpose.

It must be evident, that if any district be situated so as to receive the waters flowing off from surrounding eminences, it will eventually be converted into a morass unless an outlet be provided. Should the district be small, this object may be effected, as before, by the formation of absorbing wells placed at the lowest points; but when its dimensions are considerable, the first operation to be performed will consist in forming a ditch all round the marsh, so as to intercept the waters flowing from the upper lands, and at such an elevation, and with such a fall, as to insure the discharge of any waters which may be poured into it either from above or from below. The banks, sides, and bottom of this ditch must be formed of impermeable materials. The ground contained within these banks must then be drained in the ordinary manner, and the drains made to converge to a point from which their waters may be withdrawn, either by means of an absorbing well, or by some mechanical contrivance, such as water-wheels, steam-engines, or windmills, setting in motion pumps, norias, or Archimedean screws.

If the marsh be owing to the existence of a river at a higher level, it must be treated in a similar manner to that just described, if the river itself cannot be diverted; or the river must be confined within impermeable banks, and the waters draining from the low lands poured into it by some of the above-mentioned engines. It may, however, happen that the stream traversing the marsh may be subject to great and sudden floods; and in such cases it is necessary to form a double row of banks, of which the outer ones must be placed at a distance and superior elevation sufficient to carry off the increased volume of water flowing through them at such periods. The first banks then serve to contain the river in its normal state, the second will serve to contain it during floods; the intermediate bank, or zone, may be devoted to the cultivation of aquatic plants, such as osiers, willows, &c.; or it may be drained by a separate system from that of the marsh entirely protected.

Of the machines used to raise water in any of the supposed cases there are many varieties. Those hitherto applied may be stated to be—1, pumps; 2, Archimedean screws; 3, machines with buckets; 4, water-wheels with buckets, or what are called flash-wheels; 5, the water-pressure engines, hydraulic rams, rope pumps, &c.

Of these, the pump is the most effective when large bodies of water are to be raised from great depths, but it is exposed to the objection that the maintenance of the packing of the piston and of the pump-barrel must be very expensive when the water to be raised is so much charged with earthy matter as must always be the case with that flowing from drains. If, therefore, the height to be overcome do not exceed 15 feet, it is usual to adopt other machines. Thus, in Holland the Archimedean screw is mostly used, when the height varies from 7 to 12 feet, and in the majority of cases motion is communicated by windmills; when the height varies from 3 feet 6 inches to 7 feet, however, flash-wheels are employed. In our own fen districts the scoop has been applied by Mr. W. Fairbairn, with remarkable talent and success, in cases where the height to which the water had to be raised varied from 12 to 15 feet. In the East the noria (a machine consisting of an endless chain bearing a series of buckets, dipping into the water at the lowest point of its course, and pouring it out as it passes the upper point) has been used from time immemorial. The fifth class of machines enumerated above are so seldom used for drainage purposes that it is not worth while to dwell upon them at present. Indeed, local circumstances must modify so considerably the ground of the choice of any one or other of these mechanical means of removing water, that it is dangerous to attempt to lay down any general law upon the subject. The price of coals, the motive power of a neighbouring stream, the more or less favourable position of the locality so far as the action of the wind is concerned, the price of labour, and an infinite number of other details, may differ so greatly in any two given cases as to render very different modes of action necessary, or at least advisable.

Perhaps the most gigantic operation undertaken for the purpose of draining lands receiving the waters from other districts is the one connected with the drainage of the Harlaem Meer; and although it is rarely that engineers are required to operate upon so large a scale, a description of the method adopted is subjoined, because in principle it is identical with that required even in smaller operations of the same description.

The Harlaem Meer, or lake, owed its origin to the excess of the rain-fall over the evaporation from the district around it, so that the waters, accumulating in the depression forming the lake, spread annually to such an extent as to absorb of late years about 150 acres of its former banks. In the beginning of the sixteenth century the area was considered to have been about 9140 acres; in 1839, when it was decided to attempt the drainage of the lake, it had increased to nearly 45,000 acres, with a mean estimated depth of about 13 feet. The works are being executed by the Dutch Government, who expect to be partially repaid by the proceeds of the sale of the land.

The first operation consisted in the formation of a channel for the purpose of isolating the waters of the lake from those of the surrounding country, and at the same time of serving as an outfall for the waters to be raised. This channel is about 37½ miles long, with a width varying between 125 and 138 feet, and with a depth of 10 feet, and gave rise to great difficulties owing to the want of materials fitted for its construction. Even now it cannot be said to be impermeable, and the filtrations through it must ever remain a cause of expense and probable danger. Three large steam-engines, of about 400-horse power each (nominal), raise the waters from the lake into the canal, and are stated to be able to discharge about 238¾ cubic feet per second. They are single-actioned engines, working expansively, upon the Cornish principle, and give motion to a series of pumps working at a single lift. Two smaller machines, of about 200-horse power each, are used occasionally to discharge the water from the intercepting channel, when, owing to any extraordinary tides or high winds, the natural flow from the latter is interrupted. These machines give motion to a series of flash wheels, which raise the water about 3 feet 7 inches.

The pumping was commenced, upon a large scale, in the month of March, 1849, and in August, 1851, the water in the lake had been lowered 10 feet 2 inches. It was expected that the remaining portion would be removed within a few months, and that the drainage of the bottom, and the consolidation of the banks would then be rapidly executed. The cost of these works was estimated to be, when complete, between 600,000*l.* and 680,000*l.*, or, at the higher estimate, about 15¼*l.* per acre.

In Ireland, some large bogs have been drained upon the system adopted in reclaiming the bog of Allen, by withdrawing the water from below, and in this case it was attended with considerable success. The surface was firstly divided into fields of an oblong figure, and of about 5 or 6 acres area, by open drains. Auger holes were driven at distances of about 33 feet down to the rock, and at a level of at least 1 foot above the surface of the water in the drain. Curved pipe tiles, 1½ inch diameter, were inserted into the holes, so as to throw the water into the centre of the drain. These drains were made about 6 feet deep. On the Chat Moss drainage, no effort was made to withdraw the deeper-seated waters, but all the measures adopted were designed merely with reference to those flowing upon the surface. Square enclosures were formed, 100 yards long by 50 wide, by means of large open drains, 3 feet 9 inches deep at the minimum, 3 feet wide at the top, and 1 foot 8 inches at the bottom. Covered cross drains were formed, communicating with the open ones, and with a width of between 12 and 14 inches as far as the shoulder, placed about 2 feet 2 inches from the surface; below which point they were carried to a further depth of about 16 inches, with a width of 8 inches: these cross drains were placed at distances of about 6 yards from center to center. No tiles or pipes were used, the bottom of the drain filling being formed by the surface spit raised from the moss.

It frequently happens that large tracts of alluvial deposits are found at the mouths of rivers, which are alternately covered or left bare by the tides, and which, generally speaking, continue to increase until they attain such a height as only to be affected by the spring tides. These banks then become covered with a species of marine vegetation, and are cut up into innumerable small creeks, which, at the low-water, serve as channels for the inshore streams. Many banks of this description have been reclaimed from the tidal action, both in our own country and in Belgium and Holland, with such signal advantage, in many cases, as to cause regret that others should still remain unproductive.

The works usually required to reclaim these foreshores consist, firstly, of an embankment forming an enclosure to protect them from the sea, which must be able not only to resist the hydrostatic efforts of the external waters, but also the more destructive action of the waves and the currents; secondly, of the system of drainage of the enclosed lands, including under this head occasionally the arrangements for introducing waters charged with fertilising matters, an operation performed in some districts, and known locally by the name of "warping."

The enclosure banks are made, generally speaking, from 2 to 4 feet above the high-water line of the equinoctial spring tides, with a minimum width of from 3 feet 6 inches to 7 feet at the crown. The outline of the bank in plan must depend upon many local circumstances; but, theoretically, it will be found to offer the greatest resistance to the normal action of the waves if it be convex seawards, whilst the stability of the materials, if it be executed in stone rubble, will be the greatest if the outline be concave. Whatever be the form given in plan, it must always be borne in mind that no sharp internal angles should be allowed, and that every projection must be joined into the body of the work by gentle curves of the largest possible radius.

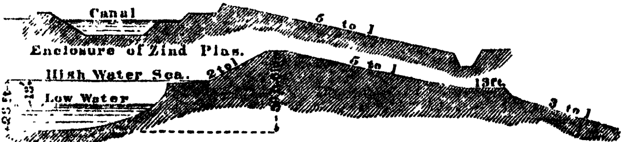
The best form of the sea slope is a subject still much in discussion amongst engineers. On the shores of Holland and Belgium the practice has been, for many years, to make it rectilinear, and inclined at a small angle to the horizon. Although these slopes have succeeded in some positions, there are others in which the results obtained have been precisely of an opposite character, and in which it would appear that a vertical wall would have been preferable. Again, many distinguished engineers are of opinion that the best form to be given is one similar to the outline the materials themselves would assume if left to arrange themselves by natural causes; whilst latterly Colonel Emy has advocated, with considerable ability, the theory that a concave transverse section was the most fitted to resist the action of the ground waves.

Long fore slopes possess the advantage of allowing the employment of any sand, or other similar materials; they offer the least resistance to the action of the sea, and are precisely the less exposed to injury in proportion as their inclination is greater. It has been observed that the destructive action of the sea exercises its greatest effect about the level of the lowest high tides of the neaps. But if these long slopes possess some advantages, they are accompanied by corresponding disadvantages; for they conduct the waves to much higher points than they would otherwise reach, and it is not always that either the materials at hand or the space disposable are such as to allow of their economical execution, to which consideration, after all, the decision as to works of this description must be referred.

Vertical inclosure walls occupy the least space, and expose the smallest surface to the action of the waves; and these again, instead of breaking upon the shore, are reflected towards the open sea. But walls of this description must encounter the maximum effort of the waves, wherever these do strike, and their recoil must act very injuriously upon the footings, unless they be of a very resisting description. The concave walls recommended by Colonel Emy have not yet been tried in a sufficient number of cases to justify any definite conclusions as to their merits; but they are in many cases objectionable on the score of the ground they require, and the great expense, not only of the first cost, but of the repairs.

The reasons which should influence the choice of the form to be given to the sea slope of an embankment may be resumed as follows. 1. It will be influenced by the main direction of the winds, waves, tides, and currents, which should be made to strike the bank as nearly as possible in a direction normal to the surface of the facing. 2. By the materials to be procured in the neighbourhood. 3. By the surface of land which can be devoted to the formation of a bank. 4. And principally by the commercial considerations affecting the original execution, the maintenance, and the value of the whole operation.

The inner slope of the banks will depend upon the materials of which it is composed; and at its foot a catch-water drain must be formed to collect the waters falling upon the inclosed land, and to conduct them to the outfall. The Dutch engineers usually make the slope about 5 to 1, and they form a roadway about 20 feet wide between its foot and the edge of the catch-water drain. When the bank is formed of mud or



Enclosure of Zind Plas.

silt, it is necessary to carry up in its center a core of sand or other hard substance, to prevent rats or moles from boring through it; and means must be taken to cover the exposed surfaces with vegetation of a character to bind together the materials of which the bank is made.

The land waters collected in the outfall drain are let off by means of sluices, whose apertures will be regulated by the quantity to be discharged, and the duration of the period in which the flow can take place, as well as by the head of water which may exist at the commencement of the discharge. Upon the sea coast the intervals between the tides recur with great regularity; but in the upper portions of river-courses the casual floods are likely to prevent the discharge during periods of variable duration, so that in many such positions it is very probable that the reclaimed lands may be partially, or entirely, flooded on all such occasions: the cultivation to be adopted must be regulated with a view to these contingencies.

The simplest mode of closing the outfall drain is by a sluice upon hinges, fixed at the outer end of a culvert, in wood, masonry, or iron, passing through the body of the bank. The floor of this aqueduct is placed at the level of the bottom of the catchwater drain, and it has an inclination outwards. So long as the head of water upon the outside of the sluice is greater than that upon the inside, it will remain closed; directly the waters upon the outside have fallen so as to form a sufficient head upon the inside to overcome the friction of the hinge, the sluice will open and give passage to the waters. It is, however, advisable, that a sliding gate working in a valve be placed behind the hinged sluice, to guard against the possibility of accidental derangements of the latter.

Another description of gate frequently used in these works is the gate working upon a vertical axis and shutting against a rebate, in which the areas of the two portions of the gate are made unequal. When the waters on the outside are higher than those on the inside, the gates are pressed against the rebate; when the opposite conditions occur, the gates open and afford a passage to the land waters. Sometimes in large gates of this description where two leaves are employed, they are made to meet at an obtuse angle, like the leaves of a lock gate.

The system of warping is much adopted on the banks of the Humber in our own country, in Tuscany, in the valleys of the Chiana and of the Rhone; and, indeed, the cultivation of the valley of the Nile is but an illustration of it upon a very extensive scale. It is founded upon the principle that all rivers carry, in their downward course, the earthy matters they derive from the lands surrounding their water-shed. The waters so charged are allowed to flow over the land to be warped, and they are retained upon it until the earthy matters are deposited, when they are allowed to run off by means of surface weirs.

It is usual to surround land proposed to be thus treated by an embankment, in which are placed the inlet sluices, at the lowest level. The water enters through these sluices at the highest point of one tide, and is retained during the interval between two successive tides; to be then run off entirely, even from the ditches, before the influx of the next. Upon the banks of the Humber it is considered that the most beneficial effects are produced by the execution of this operation between the months of June and September; the embankments are made from 3 feet to 7 feet high, and it is usually calculated that a sluice, with a clear water way about 6 feet high and 8 feet wide, will suffice to warp a surface of from 60 to 80 acres. In this district it is found that the warped lands are at first cold and raw, and that they require a peculiar treatment for agricultural purposes. Thus, they are not favourable for the growth of corn; oats may succeed upon them, but barley never will. The rotation usually adopted is as follows:—The new warp is sown with grass for two years; on the third year wheat is sown; on the fourth, beans; and on the fifth, wheat again. Should the ground thus warped be found to contain too much salt, it must be exposed to the air for some time before being brought into cultivation; and at all periods it is found to be objectionable to allow the salt warp to deposit upon growing grasses. Indeed, in Yorkshire, it is customary to let the newly-warped land lie fallow for twelve months before sowing the grass, and to let on the waters after the second crop of wheat has been raised.

The quantity of sediment brought down by the rivers falling into the Humber is enormous. Lord Hawke stated, in his Report on the Agriculture of the West Riding, that one tide would deposit an inch of mud, and the source from whence it is derived is still a matter of great uncertainty. At its mouth the Humber is as clear as most rivers, and the floods from the upper countries, so far from increasing the quantity of matters in suspension, on the contrary exercise a very injurious effect upon them. In the driest seasons and the longest droughts it is found to be the best and most plentiful, and produces its effect totally irrespective of the subsoil. In fact, a new soil is formed, and the operation of warping differs in this respect from ordinary irrigation, which acts by improving the soil already existing.

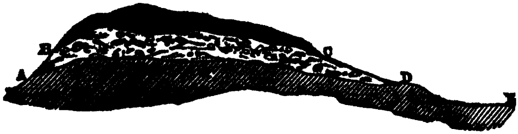
THE DRAINAGE OF TOWNS is a subject of such manifest interest to the community at large, that the discussion of the best and most efficient system to be adopted has occupied the attention of legislators and engineers at all times. There are two branches of the subject which may be considered to be sufficiently distinguishable from one another for the purposes of classification, and which may be, and often are, treated in practice upon very different principles. These subdivisions are—1st, the consideration of the means for removing surface or drainage waters; and, 2nd, of the consideration of the means of removing all excrementitious matters in such a way as to ensure their most effectual removal without annoyance, and their economical adaptation wherever possible.

Wherever a large and highly-civilized community assembles it becomes frequently difficult to separate the two classes of matters to be removed, especially as existing municipal arrangements complicate the question in an infinite number of ways. Cities grow, without much apparent reason for the particular manner in which the increase affects their plan; very rarely, indeed, is it possible to predicate, and to provide for, the eventual wants of their population; not only because the distribution of cities may alter, but also because from time to time changes are effected, even in national habits, which defy all previous calculation. Thence it is that we find both the want of systematic arrangement in our own country, and the excess of it in France, equally sources of difficulty in the adaptation of modern refinements. But we have at least this advantage—that having done little, we have less to undo; and, after all, it appears to be the wisest course to deal with these questions as they arise, without endeavouring to restrain the freedom of action of those who are to succeed us.

However, in all modern cities the tendency certainly is to divert house sewage into the public drains, especially in our own country. There are still many towns in which the old system of drainage for surface waters, and cesspools for house refuse, prevails; but, compulsorily, they are diminishing in number every year. There are some conditions which render it doubtful whether the concentration of the two systems in the same discharging drains be desirable, at least under all circumstances; and in this, as in all other branches of engineering, no inflexible rule can be said to exist. Owing to the nature of the soil upon which a town is built, its configuration, the character of the outfall, and of the country round that outfall, a course highly advisable in one case might be objectionable in another. These modifying causes will be examined successively; stating before so examining them the general conditions to be fulfilled. Some of these considerations will be found to apply to the discussion of the questions connected with the water supply of towns.

The conditions required to be fulfilled are, as before stated, that the whole of the surface and land waters be removed, and that the house refuse be carried away effectually and inoffensively. The latter will depend, in quantity, upon the population, and the greater or less abundance with which water is supplied for domestic use. In England, it is only in exceptional cases that the average number of inhabitants per house exceeds 6; whilst in France and some parts of Scotland it may be occasionally as many as 40. Upon a copious distribution of water being effected, it is usual to calculate that every individual would give rise to a consumption of about 20 gallons per day; and probably of this total quantity about 16 gallons may find their way into the sewers from the various dependences of houses. Sewers, then, if designed to remove all waters, must be of sufficient capacity to discharge a volume calculated upon the above supposition, together with any storm-waters which may fall It has been observed by Mr. Phillips, that the greatest flow of house sewage takes place between the hours of 11 and 1; and that in each of those hours at least ¼th of the total daily discharge finds its way into the sewers. The capacity of the latter must, then, be made such as to discharge the greatest quantity of storm-water falling in one hour, supposing it so to fall when the house drainage also furnishes the greatest volume.

The soil upon which a town is built may influence the character to be given to its drainage, either as it may favour or impede the transmission of what are called land springs. Thus, in many parts of London, and also in the town of Southampton, there exist small elevations, the surface of which consists of an impermeable brick earth, lying upon a stratum of gravel and sand, this last again capping the stiff blue clay known as the London clay. In many other cases the upper stratum of brick earth is wanting, and the gravel forms the immediate surface stratum; whilst in others, again, both are wanting, and the London clay is entirely exposed. The drains and sewers to be laid in between the points B and C, of such a formation as is represented, need not be made of a greater capacity than is required to remove the surface or the house waters supplied by the district; but those to be laid between C and D, and still more those between D and E, must be able to receive the waters filtering through the bed of gravel. Near London, the exposed surface of gravel is generally so small that the water yielded by it does not require to be taken into account; because the dimensions given to the sewers to enable them to carry off storm-waters are more than sufficient to relieve the strata traversed by these springs, which are necessarily characterized by a certain degree of regularity in their flow. At Southampton, however, the extent of superficial gravel is, proportionally, infinitely greater; and it is found that, after a continuance of wet weather, the whole of the lower portions of the gravel become charged with water to such an extent as to inundate all the basements below the level of the natural ground, unless where large sewers are formed, so as to intercept the flow of the subterranean waters.



In some parts of Paris the same phenomena occur upon a larger scale and with greater regularity than in the cases above cited. There a considerable portion of the city is built upon what formerly constituted a marshy plain, between the river and the hills of Belleville and Montmartre. The lowlands are situated upon a calcareous formation, called geologically "the lower fresh-water limestone," which allows the water to infiltrate with great difficulty; and the several hill sides are successively formed of the gypseous deposits, with their associated marls, capped by a deep stratum of sand and sandstone, occasionally covered by the upper fresh-water limestone. In the direction towards Belleville the sands occupy a considerable breadth of country, and receive a copious supply of water during the rainy seasons. At the same time the various hills present steep escarpments, so that the storm-waters, falling upon them, flow away with great rapidity. It follows, from these combined circumstances, that in order to obviate any inconvenience from these respective sources, the intercepting culvert, executed along the line of greatest depression, has been formed of much larger dimensions than the area it immediately drains would appear to require, without, however, preventing the occasional flooding of the lower parts of this quarter of Paris.

If the geological structure of the soil of a town in some cases appear thus to increase the difficulties connected with its sewerage, there may be others in which it produces precisely opposite results, so far at least as the removal of surface waters are concerned. Thus, in Weymouth, the portion of the town constituting the ancient Borough of Melcombe Regis, is constructed upon what is, in fact, the shingle bar thrown across the mouth of the Wey. All that is required, then, to remove the surface waters, is, to form openings through any paved roads or courts—absorbing wells, in fact—and the waters immediately sink to the level of the sea. In some parts of Liverpool, also, advantage is taken of the absorbent nature of the gravel, to allow the surface waters, to soak into it; for the drains are occasionally executed, in the lower portion, of bricks laid dry, whilst they are only set in mortar in the upper portion.

The configuration of a district, meaning by that term the general conditions of its division into subordinate districts of hill and dale, will also influence the system of sewerage to be adopted, insomuch as it may affect the number, dimension, and direction of the main sewers. New and distinct outfalls may be required for the several portions, and, frequently, according to the final mode of disposing of the sewage, distinct establishments may be required for its preparation.

The influence of the outfall is very great, for it may easily be conceived, that if a system of sewerage be made to discharge into a watercourse flowing always in one direction, as in the case of all cities situated upon rivers above the tidal range, provided the outlet be so situated as to insure a constant flow, no necessity can exist for providing against an accumulation of the sewage waters. But in tidal rivers, it frequently will occur that the mouths of the sewers will be blocked up by the rise of the tide, for intervals, varying of course with the peculiar laws of the tides in the precise locality, and with the levels of the mouths. It becomes necessary in such cases to construct the lower ends of sewers so discharging, of sufficient size to admit of their containing the waters at any time likely to flow into them during the intervals of their suspended discharge; and also to make them of sufficient strength to resist the hydrostatic pressure of any accumulation in their more elevated portions. It is to be observed, that the above reasoning only applies in those instances where the sewage is poured into the rivers directly, without being in any manner usefully applied, either in the arts or in agriculture.

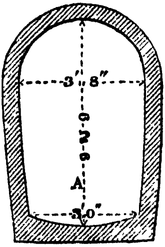
The quantity of storm-waters flowing from any given district within a given time, has frequently been alluded to as one of the most important elements in the determination of the size of the sewers. It is naturally very variable, not only according to the latitude of the localities considered, but also according to particular seasons of the year: it depends, in fact, upon the frequency and the violence of sudden atmospheric changes, rather than upon the average state of the weather; and, as the sewers must be constructed so as to carry off the maximum rain-fall, the ascertaining accurately what the latter may be is an indispensable condition for the determination of their capacity.

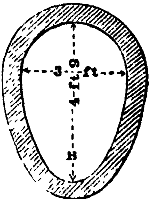
In the commencement of this Section, the average distribution of rain in different localities was treated of in a summary manner. It may suffice, then, at present to observe, that torrential rains occur with the greatest frequency in countries near the tropics, but that higher latitudes are by no means exempt from them. At Rome, where the average annual fall is about 2 feet 8 inches, showers have been observed of 17 hours' duration, with a total fall of not less than 5 inches. At Marseilles, in a shower of 14 hours' duration, 13 inches of rain have fallen; and at Arles, in 12 hours, nearly 8 inches. At Southampton, the greatest fall which has been noticed is about 2 inches in 10 hours; whilst in London, as much as 6 inches of rain have fallen in 1½ hour. The latter observation would appear to have been influenced by some very exceptional phenomenon, perhaps of the character of a waterspout; but it appears, from numerous other observations in England, that storms of a similar nature to that mentioned as observed at Southampton, are of sufficiently frequent occurrence to justify the assertion of the rule, that "when sewers are constructed to carry off storm-waters, they should be of a capacity to discharge a proportion of a 4-inch rain-fall in 24 hours, varying according to the character of the district."

The proportion so flowing into the sewers will depend upon whether the district be rural or urban; and, in the latter case, upon its configuration and the degree of permeability of the soil. It is usually calculated, that in the open country about ⅓rd of the rain-fall finds its way directly into the natural watercourses; in ordinary country towns about ⅔rds are estimated to flow at once into the sewers; and, perhaps, in large densely-populated towns, it would be safer to calculate upon ¾ths of that quantity as likely to reach them.

If a demand existed for the application of sewage manure to agricultural purposes, and if a sufficiently copious household supply existed to insure the flushing of the drains, it would unquestionably be preferable to keep the two classes of sewage distinct, because the casual introduction of large quantities of storm-water must superinduce an irregularity in the quality of the sewage, which could not fail to be prejudicial to its application. Unfortunately, there appear to be difficulties attending this practical application, at least in the present state of agricultural and engineering science; and, notwithstanding the bold assertions of some modern authorities, who from their position might fairly have been expected to exercise greater reserve and discretion, all the attempts to apply liquid sewage manure have been hitherto most signal economical failures. The separation of the two classes would produce in many cases an additional advantage, from the fact of the smaller sectional area required for the sewers, and, consequently, from the increased fall, or, where that could not be obtained, from the greater elevation at which the outlet might be established.

The form to be given to sewers may sometimes require to be different from what it is at others, owing to the necessity which may exist to visit and cleanse those which have not either a sufficient fall or a sufficiently copious supply of water to keep themselves clear. The only invariable rule to be laid down upon this subject is, that "the wet contour should be made to bear the smallest possible proportion to the sectional area," for the simple reason that the friction is always in the direct ratio of the surface upon which it acts. It follows that, wherever it is possible so to execute them, sewers should be made of a circular section. For house sewers there can be no difficulty on this score, because the introduction of the tubular drains has furnished not only the most efficient, but the most economical, means of execution. The only remark which appears to be required on this subject appears to be that, at the present day, the tendency is to execute them too small; and that there is danger of their choking if used of less than 4 inches in diameter. For secondary main drains the same system of tubes may be applied to a certain extent; but when the length becomes considerable, there will be found so many probabilities of obstruction, and so great danger from the accumulation of gas evolved from the water, that it is very questionable whether tubes should ever be used without the formation of side entrances for their examination and repair at maximum distances of $\frac{1}{8}$th of a mile, or without frequent opportunities of communication with the atmosphere. Contrary to the fashionable theory, it may perhaps be more advisable to construct a main drain, intended to receive several secondary mains, of sufficiently large sectional area to allow of its being visited and repaired without entailing the necessity for opening the ground. The form of main sewers adopted in different countries varies, as may be seen from the annexed sketches,





of which A represents the section of the main sewers used in Paris; B represents the section lately adopted in our own metropolis. The former is more convenient for the operations of workmen, whilst the latter is certainly less likely to require cleansing, because the scouring action of the water is made to operate more forcibly upon the materials brought into the sewers.

Whatever be the form of sewer adopted, the dimensions should always be calculated so that it should be able to discharge the maximum quantity it can ordinarily receive without being more than half full. The inclination to be given to house sewers should be, at the minimum, 1 in 144, or 1 inch in 12 feet; that to be given to submains, also at the minimum, 1 in 480, or 1 inch in 40 feet; whilst the inclination to be given to main drains may occasionally be carried as far as 1 in 2300, although it is decidedly preferable to keep within the limits of 1 in 1000. All junctions should be made so that the axes of the secondary sewers should be portions of circles tangential to the axes of the main sewers, and of the largest radius it is possible to obtain. Side entrances should be formed as closely as possible to the points of intersection of the respective sewers.

The collection and disposal of sewage must, evidently, from what has been said before, be entirely guided by the demand for the materials so obtained; and, hitherto, they have all been wasted in England. This is the more to be regretted, because in France, Germany, Belgium, and Italy, the manure so allowed to run to waste in England is found to be highly beneficial, and in our own country all manures are expensive. Near Edinburgh some attempts have been made to apply the sewage, by irrigating meadows with the water from sewers, yet the results there obtained are far from such as are likely to guide us in the selection of any general course of proceeding. The mode of application at Edinburgh is stated, in fact, to be very objectionable, on account of the foul smell given off; and it is also to be observed, that it rarely happens that any extent of meadow land can be found near large towns, under the necessary conditions of level to allow of a similar application by mere gravitation. Fairly, the disposal of sewage is the great problem still to be resolved by all parties connected with this branch of engineering; the very injudicious assertions of the advocates of certain theories have hitherto only indisposed the public mind to its examination.

In the case of Edinburgh, the storm and house waters were conducted together upon the meadows irrigated by the sewers. It was found, however, that there was too much manure in the contents of the latter, and it became necessary to form catch ponds, in order to enable it to deposit; and it must be borne in mind, that in the days when these ponds were formed (1829), the habits of the Scotch people were not such as to cause the bulk of the house manure to find its way into the sewers. The grass from these meadows was cut from four to six times a year, a result so little surpassing what might have been obtained by ordinary irrigation, that there is little reason to induce any person to incur a large outlay in order to obtain similar privileges. In the neighbourhood of Milan nearly the same results were obtained, for the waters of the Naviglio Grande, which receive the small quantity of house sewage continental habits allow to flow into watercourses, were found to be too rich at first, and after deposition not to produce much greater results than those derived from any other stream, so far, at least, as grass lands were concerned. Upon corn lands, the application of the comparatively highly-diluted manure of sewers seems to be of very questionable advisability, whilst, at the same time, it is to be observed, that the price of land in the immediate neighbourhood of large towns rarely allows of the cultivation of what may be called bulky crops.

It appears that the common sense of the disposal of sewage matters consists in obtaining the deposition of the fertilizing properties they may possess, and in securing them in the most portable form. The great difficulty to be overcome lies in the ammoniacal salts, which no system hitherto proposed has succeeded in obtaining in a permanent form. The use of lime water may cause the precipitation of organic matter, but the salts of ammonia in sewage waters usually exist in the condition of the carbonate, and there is not a sufficiently preponderating affinity between the lime and the carbonic acid gas to cause the latter to quit its combination with the ammonia to join the lime. Perhaps the use of the sulphate of lime or the sulphate of iron might be attended with more satisfactory results.

In France, the system adopted in dealing with the whole question of sewage of towns, is, to separate the rain and surface waters from those derived from water closets. The latter description of sewage is collected in cesspools, made as impermeable as possible, and from which it is extracted whenever required; or it is collected in large casks placed in cellars and communicating with the soil pipes. The contents of these different descriptions of cesspools are carried to large lay stalls at Montfaucon and Bondy, and allowed in the former to settle in vast basins or reservoirs, two in number, with a close dam between them, so that one may be used whilst the other is being emptied. The liquid upon the top of these reservoirs is drawn off by sluices, and passes successively into not less than seven other basins, in which it is treated in various manners, for the purpose of causing the deposition of any matters in suspension. The area of the upper reservoirs is about equal to 2½ acres superficial, with a depth of about 12 feet; the area of the lower reservoirs is about equal to 13¼ acres. From the last of these the waters are allowed to escape into the main sewer running through the low lands at the foot of Montmartre. At Bondy, the system of dealing with the manure is in principle similar to that employed at Montfaucon; and in both, the solid matters deposited at the bottoms of the reservoirs are placed in the open air to dry into powder, before being used.

Such also is the mode of dealing with sewage in use nearly all over the Continent, and to a certain extent, far too great, even in our own country. Anything more economically absurd, or more injurious to public health, it would be difficult to imagine; and, excepting that some use is made of the manure, the whole system may be cited only as a model to be avoided. Cesspools are always objectionable, because they retain a permanent source of infection whereever and however constructed. The operation of cleansing them is always disgusting and injurious, whilst the foul exhalations from the depositing reservoirs contaminate the air to a great distance around. Add to this, that, in the operation of drying the deposit, the volatile salts, in fact the most valuable, escape, and our surprise will be increased when we reflect that such monstrous nuisances should be retained in any civilized community.

IRRIGATION is a branch of Hydraulic Engineering, which has not received the attention from the public in our country which its advantages and results would appear to warrant. In France, Spain, Italy, Egypt, and India, however, it has for ages engaged the attention of agriculturalists and Governments, and immense national works have been executed to insure its successful application. In Sweden and Northern Germany irrigation works have been carried out to a great extent; but, inasmuch as it appears that the more temperate zones are the most adapted to insure satisfactory economical results, and that practically it is advisable to confine irrigation to countries situated between the 25th and 57th parallels of latitude, in the northern hemisphere at least, it is only exceptionally that works of this description have been executed beyond those limits.

All waters are not equally fitted for the purpose of irrigation, and a certain degree of care is required in their selection, whatever be the description of cultivation to which it may be proposed to apply them. Those which flow from forests, peat-mosses, or contain large quantities of the oxide of iron, are, if not positively injurious, at least but little adapted to this use. Those waters are the best which have been the longest exposed to atmospheric influences, or which may have traversed fertile lands able to communicate some of their properties. It is on this account that streams flowing through towns and villages are the most desirable, provided always that they do not become too highly charged with sewage. The waters flowing from granitic or primary rocks are often more advantageous than those from the secondary formations, particularly if these consist of the magnesio-calcareous deposits. The waters from the argillo-calcareous rocks, or marls, possess an intermediate character; but as the condition to be fulfilled by any water used in irrigation is, that it supply the deficiencies of the soil traversed, it may frequently happen that calcareous waters may be the most advantageous. A very simple criterion, however, exists, by which the adaptation of the waters of any particular stream to these purposes may be judged; it consists in the nature of the vegetation in the natural bed. If this be covered with a luxuriant vigorous herbage, of a good quality, the water may safely be considered to be fitted for the proposed use.

The description of soil which derives the greatest benefit from irrigation is that which is the most permeable and the most easily warmed. Compact clay lands gain the least, because they absorb the heat necessary to insure that the water should produce its greatest effect, with difficulty; and, as they are very retentive, the evaporation from them cools the ground to a serious extent. The nature of the subsoil is, however, able to modify very considerably the practical application of these rules.

The greatest advantage, economically, is derived from the irrigation of what are called natural and artificial meadows, in the higher latitudes at least; more southerly, garden grounds, rice fields, and even sugar plantations, are found to derive immense benefit from the process; and indeed it is hardly too much to say that the difference between fertile land and barren wilderness, in warmer countries, may be attributed to the presence or absence of some means or description of irrigation. The terms *natural* and *artificial* meadows, used above, are to be understood as referring to the nature of the vegetation only; the former, the natural meadows, being those in which plants of the natural order of the *Gramineæ* are principally grown, such as the *Phlœum pratense*, *Lolium perenne*, *Festuca sylvatica*, *Poa pratensis*, &c.; whilst the latter, the artificial meadows, produce plants of the order of *Leguminosæ*, which require to be sown every year, such as the *Medicago sativa*, *Trifolium pratense*, *Vicia sativa*, &c. Of these descriptions of meadows, again, the best results are obtained from those called *natural;* and, as they are almost the only ones adopted in our country, the following remarks will be confined to them.

The period of the year in which the water should be poured over the land will vary with the latitude, and the purposes to which it is to be applied. In England it is used sometimes for the express purpose of protecting the vegetation from the effects of frost, and is therefore applied in winter; but if it be desired to retain the matters in suspension in the waters, they should be used in the later part of the autumn and in the early spring, because it is at those epochs of the year that rivers are the most charged, under normal circumstances. The usual practice in the south-west of England is, to irrigate through the months of October, November, December, and January, from 15 to 20 days at a time, without intermission. At the expiration of each of these periods, the ground is left to dry during five or six days. If a slight frost should occur, the water is again immediately turned on, but the ground is left dry if there be any probability of a long-continued and severe frost. In February the length of the periods of irrigation is diminished to about eight days, and care is taken to shut off the water early in the morning, so as to allow the ground to dry during the daytime, and thus obviate any danger from the light frosts at night. In March the same precautions are observed, and the periods of irrigation gradually diminished, in such proportions that the ground shall be thoroughly dry before the end of the month. The meadows are then depastured during the month of April by sheep and lambs, and eaten barely down before May by a heavy stock. After that the grass is allowed to stand for hay, and in some districts it is usual to irrigate for a week before it is so left; but, as an invariable rule, it appears that when the grass is two inches high no more water is applied.

Occasionally the lands are irrigated after the crop of hay has been carried; but it is asserted that the grass of the aftermath is, under such circumstances, very injurious to sheep. Grass lands irrigated in summer are known to produce the rot in those animals, though cattle are not affected in a similar manner. It is known, also, that if the purest water remain upon land for any length of time, especially in spring or summer, it deposits a species of white scum, of the consistence of melted glue, which acts very injuriously upon the qualities of the grass.

Very little is known with respect to the quantity of water required to irrigate a definite surface; and indeed this must depend upon many circumstances connected with the latitude of the district and the nature of the subsoil. In the south of France, it has been calculated, an acre of meadow land would require about 1200 cubic feet of water per day during the season for irrigation; but there the land is very light, and the ground, owing to the summer heats, is very dry. In England it is almost certain that, even upon tolerably light lands, it would not be necessary to employ much more than half the above quantity. In the county of Gloucestershire the practice is, to allow a stream of two inches in depth to flow over the surface, and to dress the latter with a fall of half an inch to a foot from the feeder to the drain.

The primary conditions for the establishment of a system of irrigation are, that a copious supply of water exist at all times, and that the land to be irrigated should present such a configuration as to allow the waters to flow over it with a regular current, and to insure a perfect discharge of the water after it shall have passed over the land.

The water may be poured over the land either by means of a dam across the whole width of the channel, or by a lateral deviation, according to the water privilege of the landowner. The former course is preferable wherever it can be adopted, because it enables the water to be penned back, and thus poured over a greater surface and upon higher points; but it is necessary to pay particular attention to the effects of such a dam upon the flow of the stream, in order to avoid flooding the lands of neighbours. It must be borne in mind that the top water line of any intercepted stream is never horizontal, but that it assumes a hyperbolic curve, which may be considered to join the natural declivity at a distance varying with the inclination of the bed.

In Spain the waters for irrigation are, in many cases, obtained from artificial reservoirs, formed by throwing dams across the narrow gorges of deep valleys; and the various reservoirs constructed in many districts of England might be made to perform the same office. The construction of the transverse dams in such works is a matter of vital importance in every sense of the word, as was lately exemplified in the case of the Holmfirth catastrophe; and it is impossible to dwell too much on the necessity for the careful construction of the foundations, so as to prevent any infiltrations. When these dams are formed of earthwork, the crowns should be made of a width equal to half the height, and the base be at least three times the height. It is safer to make the principal slope on the inside, towards the water, and to form it in steps; and it would also be preferable to make the dam convex inwards. The top should be at least two feet above the highest water line; two sluices should be placed near the bottom, one to draw off the water, the other to allow the reservoir to be cleansed; and overflows should be formed to prevent the waters ever rising to the top of the dam itself. If the streams flowing in be charged with very large quantities of matter in suspension during the rainy seasons, it may also be necessary to construct depositing basins to receive the mud and sand they bring down.

The construction of large reservoirs has been treated at some length by the author, in an article upon Inland and River Navigation, inserted in the "Aide Mémoire to the Military Sciences." The reader is referred to it for a description of the precautions to be taken, and the lessons to be derived from similar works already executed. It may suffice here to state, that it is indispensable that the strata of the valley, in which it may be proposed to construct a new reservoir, should be naturally impermeable or rendered so by art, and that they should not allow of any unequal settlements in the dam. Care must also be taken to prevent the detrusion of the dam, by stepping its foundations, and by avoiding any horizontal joints traversing the whole thickness.

When a supply of water has been secured, the next operations will consist in the disposal of the ground in such a manner as to insure, firstly, that the water arrive by the culminating points; secondly, that it be distributed equally and with a proper velocity over the whole surface; and thirdly, that it be collected into the outfall drains directly it shall have passed over the land to be irrigated.

There are two systems of preparing the land for this purpose, which are known in the south-western counties by the names of bed-work and catch-work irrigation. In *bed-work* irrigation, the land is thrown into beds or ridges, in directions at right angles to the main feeder as far as possible, although that precise arrangement is not absolutely necessary. In *catch-work* irrigation, ditches are made at distances below each other, across the declivity, to catch the water flowing from the top of the field and distribute it again and again over the land. The former system is more expensive, but it is far more equally successful than the latter; because, evidently, the land receiving the water at the point where it first leaves the stream, must retain a larger portion of the fertilizing materials it may afford than those parts receiving the water, as it were, at second-hand. Catch-work irrigation, in fact, should never be resorted to but in those positions where the declivity is too great to admit of the troughs or distributing gutters being made to point down the descent.

The beds and ridges are so disposed that a ridge may be formed in the center, with a slight longitudinal fall, and the ground on either side slope away to a drain intended to receive the waste waters. The channels or floating troughs are placed upon the ridge, and communicate with the main feeders or conductors. Their inclination is usually made about 1 in 500, and practically their length appears to be confined to about 70 yards. When the surface to be irrigated exceeds that width, it is usual to form fresh conductors, so that the water should not flow over the land for a greater distance than 70 yards without being again carried into the natural bed. The usual dimensions of these channels are about 20 inches in width at the junction, and 12 inches at the end. The inclined planes on either side of the trough have inclinations varying with the nature of the soil and the supply of water. In light and absorbent soils they require to be slight, in order that the water may remain long on them and not scour the ground; in compact heavy lands, on the contrary, they should be greater. The limits of variation are between 1 in 1000 and 1 in 100, according to the nature of the ground. The width of the planes, also, is dependent upon the same considerations. The more compact the nature of the soil, the wider must be the planes, because the water can flow over a greater surface without being absorbed; whilst in open porous soils the width must be diminished. Upon the former a width of about 130 feet may occasionally be adopted; upon the latter 40 feet is the usual width. When the beds fall in one direction longitudinally, the crowns or ridges should be in the middle; if they fall laterally and longitudinally, the crowns should be made towards the upper side; and in either case they should project slightly above the planes.

The dimensions and inclinations of the drains at the foot of the planes must be made sufficiently great to insure the speedy and effectual removal of the water.

The inclination and sectional area of the conductor must be regulated by the number and position of the side floating troughs it may be required to supply, taking into account the quantity which may be absorbed by the earth or lost by evaporation during the passage through the conductor. The latter source of loss may be diminished by confining the width of the canal within the smallest limits possible. If the river carry down much extraneous matter it is advisable to give a tolerably sharp fall to the conductor, in order that it may not be deposited in the latter. An inclination varying between 1 and 1¼ in 10,000 will be found sufficient for this purpose, in the majority of cases. It is also desirable that the conductor be made as narrow as possible, in order to occupy the smallest quantity of land.

The formulæ for ascertaining the dimensions of the channel are, $Q = SV$; in which $Q =$ the quantity to be supplied; $S =$ the sectional area; and $V =$ the velocity. By transposition, this formula becomes $S = \frac{Q}{V}$, and V may be ascertained by the formula, given by Playfair, from De Prony, $V = -\cdot154113 + \sqrt{\cdot023751 + 32806\cdot6 \times RI}$; in which R is the hydraulic mean depth, or a quantity obtained by dividing the area of the transverse section, expressed in square inches, by the perimetre, or boundary of that section minus the breadth of the surface, expressed in lineal inches; and $I =$ the sine of the inclination. As the angles formed with the horizon are infinitely small, in these operations it is generally found to be sufficient to substitute the rate of inclination for the more theoretically correct term of the sine. It is hardly to be supposed that the class of workmen who usually direct irrigation works make many calculations of this kind; nor, with the superabundance of water we have in England, is it often necessary to consider the precise dimensions required. It may happen, however, that it will be found desirable to execute irrigation channels in countries where water is more valuable. In Gloucestershire it is usual to make the conducting channel, for a surface of 300 acres, about 15 feet wide by 3 feet deep. The distance between the feeders and drains, in cold swampy lands in that county, is also ordinarily confined to about 4 or 5 yards.

Hatches or sluices should be placed at the points where the conductor communicates with the stream, or where the floating troughs branch off from the conductors, so as to regulate the admission and distribution of the water at any period. The most important of these is the hatch at the mouth of the conductor, which will require to be of considerable strength in order to resist the efforts of any sudden freshets; for if these should occur when the crop is in a forward state, and bring down waters charged with much sedimentary matter, they may produce very disastrous effects. The floating troughs themselves may be closed by movable dams, or merely by pieces of turf laid across the mouth.

All the above remarks must be considered as only possessing a very general application, and as being susceptible of variation according to local circumstances. Thus the inclination frequently given to the main conductors in the mountainous districts of the Alps, Tyrol, Savoy, Dauphiné, and Pyrenees, is $\frac{1}{500}$; whilst in the private canals lately executed in Piedmont and Lombardy, it varies from $\frac{1}{1500}$ to $\frac{1}{3000}$; and in La Provence it varies from $\frac{6}{10000}$ to $\frac{9}{10000}$. It would appear that in mountainous countries, therefore, the higher limit may be adopted; but that if the inclination approach $\frac{1}{330}$, it becomes necessary to retard the velocity of the stream by a series of cascades or dams, for there are few soils that could resist its denuding effects under such circumstances; and if the irrigation take place in a plain where the river has become tolerably clear, the inclination may be made as stated above, from $\frac{1}{1500}$ to $\frac{1}{3000}$.

In setting out the main conductor, it is important that the radius of curvature of the changes of direction be made as large as possible, in order to avoid any diminution in the velocity of the flow and the rate of discharge, and also to obviate any destructive action upon the banks. The minimum radius should be from 100 to 150 yards. The banks should be kept at least 8 inches above the water line when the supply is constant; and it is even desirable to make that height from 16 to 18 inches, to guard against any inconvenience from the development of aquatic plants, which takes place with most extraordinary rapidity in all such positions. The peculiar mode of growth of these plants, in long festoons, also produces a greater interference with the rate of discharge than would arise from their precise volume; because they retard the velocity of flow, on account of the manner in which their long streamers follow the direction of the current. It is important that they should be cut as often as possible.

The establishment of gauges for ascertaining the quantity of water flowing into any conductor is an object of importance in many countries; but in our own, wherever water can be obtained for the purposes of irrigation, it usually is to be met with in such quantities as to render it unnecessary to take note of the degree in which it is consumed. The subject has been discussed in an article upon Water Meadows, in the "Aide Mémoire to the Military Sciences," in which also will be found many formulæ besides those quoted above, which are given as being practically applied by the engineers of France and Italy in the execution of this description of works.

It is necessary to construct waste weirs or overflows upon the sides of the main conductor, especially when the stream from which it is supplied is exposed to sudden and considerable variations in its volume.

Water may occasionally be obtained in sufficient abundance for irrigation purposes from artesian wells; and many works of this description have been executed in the northern parts of Italy and in France. In some cases the waters thus obtained are eminently advantageous, because their temperature is more constantly uniform than that of rivers exposed to atmospheric influences can possibly be, and their chemical constitution is also frequently of a most desirable nature. In other positions it may often be advisable to procure the water required by mechanical means; and under those circumstances one or other of the various engines already mentioned, or to be described in the next Section, may be employed, according to the particular circumstances of the case. It may be necessary to observe, that the system of water meadows so much employed in Devonshire is the *catch*-work meadow; and that they are formed by turning the water from a stream along the side of the hill, through a small cut made nearly level, and stopped at the end. As soon as the cut is filled, the water flows over the sides; and, in order to regulate its velocity and equal flow over the whole field, small parallel cuts are formed at distances of from 20 to 30 feet, which, like the main conductor, are stopped at the ends. The water flows from these cuts in the same manner as before, over the intermediate beds, and is finally received into a main drain at the bottom of the field. Narrow deep drains run from the top of the field to the bottom, at right angles to the watercourses, and at distances of about from 50 to 60 yards, for the purpose of drawing away the water from the intermediate beds, when the operation of flooding is completed. Their ends are stopped, however, when the water is to be turned on.

It is generally considered that the first cost of preparing any large surface for the execution of bed-work irrigation is about 10*l.* per acre, although the Duke of Portland's celebrated water meadows cost as much as 30*l.* per acre. Catch-work irrigation costs, on the average, half the above, or about 5*l.* per acre. The maintenance of either varies from between 5*s.* to 10*s.* per acre; and in every instance, where water meadows have been skilfully prepared, and the supply of water is tolerably abundant, the rent has been at least doubled.

G. Woodfall and Son, Printers, Angel Court, Skinner Street, London.